

THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE

A REPORT ON
CACAO RESEARCH

1953

ST. AUGUSTINE, TRINIDAD, B.W.I.



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ST. AUGUSTINE, TRINIDAD, B.W.I.

THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE

Incorporated by Royal Charter in 1926

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Introduction

THE preparation each year of a report on the progress of cacao research has one real benefit. It provides each research worker with an incentive to assess the data he has collected during the year and to determine their worth both in relation to previous work and to his objective. Having done this, he has to select those results which he considers are of value to others and then must record them in an intelligible manner in words, tables and diagrams. He must remember that others are unfamiliar with his experimental evidence and he must, therefore, present a balanced and comprehensive picture.

Research is done to improve yield and quality of cacao beans. Any factor or complex of factors that depresses yield or quality or, conversely, that may if established increase yield and quality must be investigated. These harmful and helpful factors are not always known. Does a certain insect larva which feeds on the leaves of cacao depress yield? If we don't know, then we must find out. Whether the answer proves to be negative or positive it should be recorded for the benefit of others so that they do not need to repeat the work.

It is clearly one of our functions to establish, maintain and expand a collection of species, varieties and selected clones to provide a fund of genetical material for the use of the plant breeder. From time to time we must explore new regions and collect in order to augment our stock and it is only appropriate that the results of a collecting expedition should be written-up fully in this report.

In our outlook we must think of cacao research as one entity with branches and subdivisions parts of the whole. Research on cacao soils has no value except in relation to the cacao trees growing in them. Studies on the genetics, physiology and morphology of the cacao tree have no value in themselves; they only have permanent value when correlated and when the sum of their results can be measured in improved quantities and qualities of cacao beans. Fundamental research is neither belittled nor neglected but the call for it must be to provide answers to questions which arise out of applied research. We cannot afford to do pure research just for the sake of adding to the sum total of human knowledge. Also, it is not the function of the research staff to interpret the results for local application where a territory has men on its agricultural staff, or attached to its cocoa boards, qualified and able to do this work. But where there is a gap between knowledge and its application in the field then it is a matter that deserves most careful consideration. Research workers must bring their knowledge to a condition in which it can be applied, but an advisory organisation must see to its application.

Perhaps the most important factor is the attitude of mind of the team towards their research. What is the starting point, the cacao tree in its environment? Do we study the interaction of external factors (light and shade, tem-

perature, humidity, the physical and chemical nature of the soil) with the internal factors (the genetic constitution of the tree, its metabolism and the effects of fungus, virus, parasitic insect and nematode)? Of course: but do we stop there? What is the environment of a cacao tree? Because in the wild it grows as a second or third story tree in high forest must that be regarded as its proper environment? Is our interest limited to the study of the natural environment of wild cacao? Are we not finally most concerned with the environment that is most favourable to increased yields? The growth of cacao trees in different types of soils and under different environmental conditions must be studied in order to understand every aspect of the problem. For this reason the research at River Estate is unbalanced because the soils there are for the most part light and sandy; we would welcome the acquisition of a suitable area of heavy clay land so that experiments could be duplicated and the results of both series integrated. In the meanwhile we are grateful for the co-operation of the Agricultural Department of Trinidad and Tobago which has enabled us to set up experiments in 1953 on the silty clay loam at Centeno. The study of these different environments is not undertaken in order to duplicate those that appear to be the best, but so that the basic factors which affect the life and behaviour of the cacao tree may be determined.

There is only one comprehensive question. In what artificial environment can a cacao tree of known genetic constitution yield the most beans of the desired quality? And the answer to this question must always be the objective in the mind of the research worker.

A brief appraisal of the situation may be of value and of interest and it is, therefore, given for the sake of clarity under three heads: research completed, research in progress and research contemplated.

Research Completed

A full and final account is given of the collecting expedition to Colombia which covered the period June, 1952, to October, 1953. It includes full notes on the different forms of *Theobroma cacao* and on thirteen other species collected, on ten species of *Herrania* (a genus closely related to *Theobroma*), on the insects, their parasites and predators, associated with these two genera, and on the incidence of Witches' broom and *Monilia* disease. Sixty-three collections of living material were sent to Trinidad many of which are now well established. No facts have been revealed in disparity with the hypothesis put forward by Cheesman, based on Pound's extensive travels, that the centre of origin of *Theobroma cacao* lies near the Colombian-Ecuadorian boundary on the eastern flanks of the Andes.

The paper by D. B. Murray, on the shade and fertiliser experiment with cacao planted in 1950, will repay careful

study. *Growth.* As light intensity increases the trees become more vigorous, but at 75% and 100% light growth is dependent on fertiliser treatment. Without additional nitrogen the plants are stunted, with nitrogen they are extremely vigorous. Growth at high light intensities, with nitrogen, results in a considerable development of lateral branches and a closed canopy whereas the growth at low light is lax. *Yield.* Mean yield increases up to 50% light and declines progressively thereafter except where nitrogen has been applied when the maximum yield is at 75% and the yield at 100% is slightly in excess of that at 50%. Plants not receiving nitrogen grown in 50% light gave more than twice the yield of plants without added nitrogen in full light. *Cropping period.* Two very important points are made clear. At low light intensities there is a steady trickle of pods and no peak harvest whereas in 50% or more light all pods mature in a peak period. Where fertilisers are given, in particular nitrogen, cropping begins earlier and there is a decided peak much higher than that of controls. *Cherelles.* The two striking features are the small numbers of cherelles that develop to maturity and the increase in numbers of healthy cherelles with fertiliser treatment. Clearly one factor in the formation and development of cherelles into pods is an adequate supply of nutrients, particularly nitrogen. The general conclusion is that on a soil such as this, which is deficient in nutrients, higher yields of cacao can be obtained by growing trees with less shade provided that fertilisers, in particular nitrogen, are used.

Soon after the cacao shade experiment was started in July, 1950, measurements of soil temperature and soil moisture were made and the effect was studied of the different depths below the surface of the soil at which gravel occurred. G. W. Smith presents the data and analyses them. He also studied the effect of mulching and of shade on soil temperature and soil moisture content. The daily variations in temperature are greater for un-mulched than for mulched plots, but mulching has little effect on mean soil temperature. Shade has a marked effect on soil temperature at a depth of three inches and is the only factor which decreased minimum temperatures to any great extent. After applying a heavy dressing of bagasse the moisture content of the top six inches tended to be greater than that of bare soil, an effect which lasted for about ten weeks. But in the second six inches the moisture content under the mulch was consistently lower throughout the whole period. The weekly variation under the mulch was smaller. The yield of cacao for ICS 1 and ICS 60 increased the nearer the gravel was to the surface of the soil, but not so for ICS 95. This is in accord with planters' experience; ICS 1 requires a good well-drained soil whilst ICS 95 is a tough clone and can survive in poor and waterlogged soils.

The insect pests of cacao obtain their nitrogenous and carbohydrate food from the host plant; there are grounds for believing that the rate of development of some of the pest-populations is very markedly influenced by the amount and kinds of such compounds that are available where they feed. In order to provide a standard, by comparison with which abnormally high or low concentrations of the nitrogenous fractions in the leaves of the host plant can be recognised, R. G. Fennah has made a study of the fluctuations in relative amounts of such fractions in the leaf from the time it opens until it is shed. His results show that the history of nitrogen partition is

the same, at equal physiological age-levels, in all degrees of light down to 15% but that, even from the day of bud-opening, the rate of change is increasingly more deliberate with increase in shade and that the longevity of shaded leaves markedly surpasses that of exposed.

A new technique for the rooting of cacao cuttings, involving the use of much less labour than other methods and, therefore, much cheaper in consequence, has been suggested by D. B. Murray. As it is a development of the process devised by H. Evans for hardening rooted cuttings it can be used also for this purpose. The cuttings, one to a basket, are inserted in a core of composted sawdust around which is packed potting soil. The baskets are arranged on shelves in a shaded glasshouse in which humidity is maintained at 100% by the use of a centrifugal humidifier. One unit, properly managed, could supply annually 30,000 plants ready for the field.

It is essential, no milder word is appropriate, that satisfactory techniques be perfected for the complete study of the contents of a single cacao pod. The micro-fermentary, described in the last report, has been further improved and it is hoped that apparatus and technique will soon be standardised. By this means the beans in one pod may be fermented separately. In the meantime the solar fermentary, originally designed by J. A. McDonald, has been modified by K. W. De Witt. This is intermediate in capacity between the normal sweat-box and the micro-fermentary. Each box in the solar fermentary can accommodate thirty to thirty-five pounds of wet cacao; turning is carried out on alternate days and on the seventh day the beans are transferred to the drying floor. The final product, of more than thirty experiments in which twenty-one clones have been represented, is a consistently well-fermented cacao.

High resistance to Witches' broom disease is only known in a few selections from the upper Amazon valley, but amongst the ICS clones there is considerable variation in degree of resistance or susceptibility. P. C. Holliday in his survey points out that apparent resistance to pod infection may be disease avoidance due to production of fruits in the drier months of the year when infection is low. In areas where the incidence of the disease is expected to be heavy ICS 6, 45, 91, 95 and 98 should be grown and ICS 3, 4, 9, 16, 53 and 60 which are very susceptible should not be grown.

P. C. Holliday reviews losses due to Witches' broom disease and their control by spraying. In Trinidad most serious losses occur from October to March. As symptoms do not show until three months after infection, spraying should begin in late June and continue until December. The spraying technique is described with six different fungicides and results of treatment analysed. Bordeaux proved to be slightly superior to Perenox. Whilst lime-sulphur gave good results at one estate it does not control *Phytophthora* (Black pod) as do the copper-containing fungicides. Unless pod-infection rate is at least 15% to 20%, in a field yielding 800 lbs., or more, of dry cacao per acre, spraying is unlikely to be profitable to control Witches' broom only—brooms still have to be removed by hand and by this means, with less susceptible clones, the disease can be controlled—but where Black pod is severe a spraying schedule might be devised to control both diseases.

When, as occasionally happens, a minor leaf-eating pest appears in noticeable quantity it is apt to be regarded as a new menace and the property-owner appeals for information. T. W. Kirkpatrick has done a useful task of fact-finding, and the results may henceforth be used to furnish the necessary reassurance. Only one of the numerous butterfly and moth caterpillars that feed on cacao in the field has ever been found to be sufficiently abundant to cause appreciable injury, but as any one of them may turn up he appropriately describes the larvæ of them all.

A paper by R. G. Fennah presents a new approach, combining both ecology and physiology, to the study of the larvæ of the cacao beetle, *Steirastoma breve*. He shows that, as a result of a study of the nine hundred and sixty trees in the shade experiment planted in July, 1950, there is a highly significant increase in the number of trees bearing larval tunnels of the cacao beetle with increasing light intensity. Oviposition followed by successful larval establishment is much higher on exposed than on shaded cacao. What are the reasons for this? Three possible effects of high insolation require investigation: 1, increased water-stress; 2, increased carbohydrate content; and 3, increased metabolic rate. Results of a detailed study of the second of these show that adults and larvæ can digest carbohydrate only in its soluble forms; these are present at a low level in the living thin bark on which adult beetles feed; the highest concentrations are likely to be present under conditions which permit maximal photosynthesis, i.e., when there is a high degree of exposure to sunlight. Unshaded cacao may thus be expected to provide a more nutritious pabulum for the larvæ and possibly a greater gustatory stimulus to the adult.

The paper by G. Havord, G. K. Maliphant and F. W. Cope should be studied with the two papers in the last two reports. The first results of the two oldest of the series of experiments at River Estate, planted July, 1949, are presented and discussed. The main results are the much increased yields of wet beans per acre from closer spacing due to the larger number of bearing trees and a marked response to nitrogen and phosphate fertilisers which resulted in a larger number of pods per tree—the effect was greater on the wide-spaced plots and the effects of nitrogen and phosphate are additive. Where treatments resulted in an increase in crop, the yield per pod showed a reduction. Closer spacing and nitrogen fertilisers both slightly increased the percentage of diseased pods. The lack of response to potash is surprising. None of the mulch treatments gave a significant yield response. ICS 1 grew better and yielded much more than other clones especially at the closer spacing.

Other paper

A paper entitled "Aggregate Stability in a Clay Soil in Relation to Cacao Cultivation," by G. Havord, T. E. Wasowicz and R. G. White, was published in the July issue of *Tropical Agriculture*, volume 31, pp. 233-241.

Research in Progress

Stock-scion clonal grafts

F. W. Cope and D. B. Murray have continued their investigations into the grafting of the scion of one clone on to the stock of another. Earlier work reviewed by Cope

and Murray, 1952, has shown that a high yielding clone on its own roots (i.e., a rooted cutting) yields more than if budded on to the stock of unselected seedling rootstocks. Presumably a good clone has a more efficient root system than a poor clone. Further work has shown that whilst incompatibility has not been observed between clones the growth rate above and below the union of scion and stock varies. The interesting feature is that there appears to be great consistency between reciprocal grafts, thus ICS 1 grafted on to ICS 45 stock gives strong overgrowth whilst ICS 45 on ICS 1 stock gives equally strong taper. Similar reversals hold for the other five reciprocal pairs of grafts.

Introductions

Seedlings of some potentially valuable near-criollo Venezuelan cacaos have been established. Unfortunately Lafi No. 7 has not been established; requests for material have been sent to Samoa. Requests for Grenada clones, other than the five already established, have not yet been met. *T. cacao* seedlings from the Colombian expedition have been vegetatively propagated for sharing with W.A.C.R.I. A number of the plants of *Theobroma* and *Herrania* species from this expedition have been established at River Estate and at the College.

Breeding programme

Detailed investigations have been made of some of the better Amazonian material at Marper Estate with a view to selecting ten parents for hybridisation with five ICS clones as part of the joint programme of the College and the Trinidad and Tobago Department of Agriculture of breeding for resistance to Witches' broom disease. Breeding between and within first generation inbreds of ICS 1 and ICS 45 was continued. One ICS 1 selfed progeny appears to be homozygous for axil-spot and is being thoroughly tested; if the results are satisfactory this plant may have considerable value in experiments designed to follow natural pollen transference. Progeny of ICS 1 × M 8 "crinkle dwarf" and RT 18 selfed have been established for studies in the inheritance of the "crinkle dwarf" factor and thrips-resistance respectively.

Shade, spacing and fertiliser experiment

A second shade, spacing and fertiliser experiment was planted in 1953 on a site, kindly made available by the Department of Agriculture, Trinidad and Tobago, at the Central Experiment Station, Centeno. The design and treatments are similar to those at River Estate, but four clones ICS 1, 6 and 95 and IMC 67 are planted in each plot instead of ICS 1 alone. The soil is an imperfectly drained, yellowish-brown, silty-clay, silty-clay loam or clay-loam, with a low nutrient status, acid and becoming increasingly acid with depth.

Marginal leaf-scorch

Arising from the work described by G. Rodrigues in the last report (pages 47-51) a new greenhouse experiment is in progress designed for the critical investigation of the effects of excess chlorides, lack of potassium and atmospheric temperature and humidity on marginal leaf-scorch.

Iron chlorosis

Further work is in progress on the control of iron chlorosis by the use of complex iron compounds and by improvements of the organic status of the soil.

Research Contemplated

There are many fundamental approaches to cacao problems which have not yet been tried. One involves the culture of floral-cushion tissues in aseptic media in order to find out the precise factors which result in flowering and fruit-setting. Another is a study of the physiology of growth by an investigation of the part played by the natural hormones in the establishment of fan and chupon growth and in flushing. There is evidence that competition for food between young growth, in flushing, and developing fruits is frequently the cause of cherelle wilt. Clearly, if it were possible to control the time of flushing by altering the hormone balance, cherelle wilt might be reduced and a higher crop harvested. Furthermore, if by hormone control earlier fruiting of young plants could be ensured, the results might be of great value in the breeding programme. The newly appointed junior plant physiologist has been given special training in hormone techniques in order to equip him to do this work.

Much is known about the nature and spread of the three major diseases—Witches' broom, Black pod and Cacao virus—and of the Cacao beetle, but research is required on the nature and susceptibility of the plant to specific

diseases. This is in order to evolve techniques to enable seedlings to be tested quickly and with certainty for resistance or susceptibility. A successful outcome of this research would hasten the breeding and selection of resistant strains.

Studies of representative cacao soils and environments are to be undertaken in greater detail than has been attempted hitherto. The objectives are twofold. The *first* is to study further the relationships between factors of soil and atmospheric environment and the growth and yield of the cacao tree under plantation conditions, so that limiting factors may be recognised and means devised and applied suitably to alter them. The *second* is to develop a technique which will enable large-scale land capability maps to be prepared, which may be used in conjunction with the findings of other aspects of cacao research, for the purpose of advising planters on the most efficient use of their land for growing cacao (or, if the land is unsuited to cacao, even with the use of all available cultural techniques, for growing other crops). This aspect is a natural extension of the broad soil survey the findings of which are not at present developed to the stage of being of use to the planter.

The Anglo-Colombian Cacao Collecting Expedition

by

R. E. D. Baker, F. W. Cope, P. C. Holliday, B. G. Bartley and D. J. Taylor

Introduction

FOLLOWING the recommendations of the 1945 Cocoa Conference, an expedition was organised to explore parts of the Republic of Colombia for the purpose of collecting wild and cultivated *Theobroma cacao*, other species of the genus *Theobroma* and of the allied genus *Herrania*. Negotiations with the Government of Colombia opened at the end of 1951, and in June, 1952, the first party of British scientists arrived in Bogotá. In mid-August, with two Colombian scientists attached, this party began its collecting. Thereafter, with changes in personnel, the exploring party continued its work without intermission until October, 1953.

The members of the expedition, all of whom also assisted in the compilation of this report, were as follows:—

F. W. Cope, June, 1952, to November, 1952, and February, 1953, to June, 1953.

D. J. Taylor, June, 1952, to January, 1953.

R. E. D. Baker, June, 1952, to December, 1952.

P. C. Holliday, October, 1952, to October, 1953.

B. G. Bartley, October, 1952, to March, 1953, and July, 1953, to October, 1953.

The main areas of Colombia explored were (Plate XI):—

(1) parts of the rivers Caquetá, Apaporis, Vaupés, Negro (Guainía), Inirida and their tributaries in the provinces of Amazonas and Vaupés, from 1° 30' S. to 3° N. and from 67° W. to 71° W.

(2) parts of the rivers Putumayo, Caquetá and Caguán in the provinces of Caquetá and Putumayo from 0° 20' S. to 2° N. and from 74° W. to 77° W.

(3) parts of the trans-Andean provinces of Valle del Cauca and El Chocó from 3° N. to 6° N. and between 76° W. and 78° W.

(4) scattered areas in the provinces of Antioquia, Norte de Santander, Magdalena, Santander and Huila.

For the first two parts of the expedition small parties were flown, usually by Catalina aircraft, to one of the great rivers and thereafter they travelled by boat. Some weeks or months later they would be collected, again usually by Catalina aircraft. Journeys of this nature were sometimes somewhat arduous and it was found desirable to return to Bogotá to rest and re-equip every three months or so. Apart from very occasional bouts of malaria the expedition was fortunate in keeping remarkably healthy and in avoiding serious accidents. Parts 3 and 4 of the expedition mainly consisted of shorter journeys, by air if possible, to places where cultivated cacao or wild *Theobroma* species were known or suspected to occur.

The number of botanical collections made totalled 191, of which 63 were living material sent to Trinidad. Identifications of the *Theobroma* material have been made by Prof. J. Cuatrecasas and of the *Herrania* material by Dr. Richard E. Schultes to both of whom we wish to express our thanks. We are particularly indebted to Dr. Schultes for the great interest he took in the expedition and for his invaluable help in planning and organising journeys, on many of which we had the pleasure of his company.

We also wish to thank the Ministry of Agriculture and the National Herbarium of Colombia for much help and many kindnesses and for the company of their scientists on many journeys. To the A.I.D.A. Company, and particularly to Sr. Miguel Dumit, we are indebted for arranging the transport of ourselves and our supplies to the remoter forests. Without the help and lively interest of Sr. Dumit it would be virtually impossible to have attempted botanical exploration in southern and south-eastern Colombia.

We express also our grateful thanks to the British Embassy and Consulate in Bogotá and to H.B.M. Consul in Medellin, particularly for forwarding our collections to Trinidad; to Messrs. Cadbury Bros. for a gift of vacuum-packed chocolate—a welcome addition to our rations; to H.M. War Office for the release of Compo rations, and to the many Colombians, both civilians and members of the armed forces, who helped us so willingly and showed us so many kindnesses on our journeys.

Theobroma Linnaeus

While the main interests of the expedition centred on *Theobroma cacao* the opportunity was taken to collect herbarium and planting material of the other species of *Theobroma*, to study their distribution and habitat and the relationships of the diseases of the uncultivated species and those of *T. cacao*. The number of distinct species of *Theobroma* is about two dozen. About fourteen species were located by the expedition in the areas visited. Chevalier (1946) published a classification of the genus which may be considered to be the most up-to-date. Several new species have been described since it appeared, particularly from Central America and the part of Colombia bordering the Pacific Ocean.

The genus is distributed throughout Central America and humid areas of low altitude in South America—north of latitude 12° S. With the exception of *T. cacao* and *T. bicolor*, which are to be found everywhere in the distribution area of the genus, the species divide themselves into two groups on the region in which they are found,

several species being endemic to certain districts within these areas. The first region comprises the whole area east of the Andes and may be called the Amazonian region. The other species are located in what may be called the Pacific region, which comprises the Central American countries and the parts of Colombia and Ecuador between the Western Andes and the Pacific. The Pacific region differs from the Amazonian region in that several species of the former possess yellow pigmentation in the flowers. This colour seems to be lacking in species from the Amazonian area.

The characteristic growth pattern of the genus is the development of a straight stem called a "chupon" in which the leaves are arranged in a $5/8$ phyllotaxy. The chupon branches into three parts in all species, except *T. cacao* where five branches are usually produced. This area of branching is known as a "jorquette." The branches are often referred as "fans" and have $\frac{1}{2}$ phyllotaxy.

The species may be divided into two groups on the basis of the type of germination of the seed and method in which the stem continues to grow above the jorquette. In those species in which germination is epigeal as in *T. cacao* the new chupon develops from an axillary bud below the branches at the jorquette. In the other species germination is hypogeal and the chupons arise from an apical bud in the centre of the branches. The young leaves of the species in the first group are generally glabrous and those of most species in the second group are usually densely and finely pubescent.

Theobroma cacao is the only species examined in which pigmented cotyledons can occur; the seeds of all other species possess white cotyledons. The seeds of the wild species have not been used for chocolate making to any appreciable extent, but the seeds and pulp of some of the other species are used for different purposes.

No infection by *Marasmius perniciosus* Stahel was seen on the species of the Pacific region since this disease is absent from the areas of this region which were visited by members of the expedition.

Descriptions of the various species encountered by the expedition follow. *T. cacao* and *T. bicolor* are treated first, followed by those found in the Amazonian and Pacific regions respectively.

THEOBROMA CACAO L.

On the stretch of the R. Apaporis explored by the expedition, at no place were encountered any trees of this species that could be regarded as indigenous. Only two trees were seen, under cultivation in an Indian's garden, and the seeds were said to have been brought from La Pedrera. The pods were short, broadly oval, smooth surfaced and without pigmentation; the beans were uniformly dark purple and flattened.

At La Pedrera, on the lower R. Caquetá, the exploring party was shown areas on the river banks which carried irregular stands of cacao trees. The local inhabitants claimed these trees to be wild, but the remarkable way in which they were confined to the river banks in areas which almost certainly had been under cultivation at one time or another created doubts about this claim. No trees were ever encountered at any short distance from the river bank. The trees examined were undoubtedly very old; they had all several well developed trunks grown from basal chupons. The pods borne on these trees were of a pronounced

amelonado type, with a smooth, white-base surface. The biggest pod collected had dimensions 18.5 cm. by 9.5 cm. (Fig. 1), with a shell thickness of 19 mm.; there were 39 beans inside with a wet weight of 185 grams and with a rounded cross-section. Smaller pods had as few as six beans. The bean colour was predominantly dark purple. Self-pollinations carried out on five trees revealed that all were self-incompatible. Witches' broom disease (*Marasmius perniciosus* Stahel) was widespread in its incidence and no trees were seen suggesting resistance to it. No Monilia disease (*Monilia royeri* Cif.) was observed in the area. These trees were seen six months later to be standing in moving flood water of the Caquetá, a condition which was said to persist some five months of the year. A sample of seeds was sent to Trinidad.

Cacao trees were very scarce in the vicinity of Mitú, capital of the Vaupés province. Those seen under cultivation were of a type very similar to that at La Pedrera with small, flat, dark purple beans. Information was obtained at San Felipe, on the R. Negro, that the cultivated cacaos of the Guaviare, Inirida, Negro and Casiquiare rivers are all of this same type although some variation in pod shape exists. It seems very unlikely that *Theobroma cacao* is truly indigenous to this area. The contents of a few pods obtained by the good offices of a pilot visiting Amanavén (at the confluence of the Guaviare and Orinoco) were despatched to Trinidad.

One exploring party travelled down the R. Vaupés from Mitú as far as the mouth of the Papurí. Small isolated groups of trees were seen in Indians' gardens at stopping places along the way. At Yavaratá, in Brazil, and directly opposite the mouth of the Papurí, some thirty trees were seen under cultivation. The largest pod gathered measured 13.5 cm. by 7.5 cm., containing 40 flat, dark coloured beans, weighing 115 grams wet. The trees were said to have been planted from seed obtained on the Papurí. No Witches' broom disease was observed.

This same party voyaged up the Papurí. Cacao was found fairly continuously, but always planted in settlements and said to have been introduced by Dutch missions. The pods on these trees were all of the same white-base colour seen elsewhere, smooth surfaced and rather small, sometimes with a distinct bottle neck. The beans were small, flattened and generally dark purple in colour. Further towards the source of the Papurí the pods appeared somewhat to increase in size. At one old Dutch mission, pods were seen measuring 18 cm. by 9 cm. (Fig. 2), with 32 seeds weighing 120 grams. Seed collections from three places on the Papurí were sent to Trinidad. It was interesting to note that none of the trees on the river showed signs of Witches' broom attack, although this pathogen appeared to be attacking the commonly occurring *T. subincana* Mart. No definite claim for resistance can be made, however, for the Papurí cacao population since it is not impossible that the brooms seen on *T. subincana* were induced by a strain of *Marasmius perniciosus* different from that which attacks *T. cacao*. The source of the introduced cacao is not known; that it was introduced from elsewhere is indicated by the lack of a local Tucano name for *T. cacao*, the single word used to designate a *Theobroma* species referring strictly only to *T. subincana*.

It would appear highly unlikely that *T. cacao* is indigenous to the south-eastern corner of Colombia explored by the expedition. The constancy of the type encountered would suggest a provenance from a very small original population. Apart from the R. Caquetá, none of

the rivers explored has its source near the centre of origin hypothesized by Cheesman (1944) and it is, therefore, not surprising that cacao is not native to the rivers Apaporis and Vaupés.

At a later date, a party travelled by air to Morichal, situated about half-way along the course of the R. Inírida, which is a river of the Orinoco drainage system. No *Theobroma cacao* was encountered, although there were reports that it had been introduced and was under cultivation on the tributary Papunaua. The species cannot be regarded as native to the Inírida.

Explorations were also carried out in the triangle formed by the upper Putumayo and San Miguel rivers as its base and San Vicente del Caguán as its apex. The R. Caguán was covered from San Vicente to its mouth. Cacao was found under cultivation near Arbolitos, having been introduced from the province of Huila, farther west; it was a very poor type, remarkable for its susceptibility to Witches' broom disease. Below Arbolitos the river is virtually uninhabited, although the occurrence of place names on an accurate map where to-day there are no vestiges of settlements suggests that formerly the river was inhabited. Cacao trees growing wild in the forest along the banks were frequently encountered. For the reason given above, however, it is impossible to say, with complete certainty, that these trees are spontaneous, uninfluenced by man, and truly indigenous to the area. The type was remarkably uniform, bearing smooth, elongated pods with a pronounced rounded apex, no shoulder and five extremely shallow furrows. Traces of red pigmentation on a white base were observed. The pod dimensions were approximately 16 cm. by 7 cm. (Fig. 3). The shell was relatively thin, being some 7 to 8 mm. in thickness. The beans were small, elongated, rounded in cross section and of a rather dark purple coloration. The incidence of Witches' broom disease was noted. Ripe pods in sound condition were almost non-existent, monkeys and large grubs having attacked them, so that only very few seeds could be collected for despatch to Trinidad. Travelling up the R. Caquetá from the mouth of the Caguán, the exploring party encountered more cacao trees, differing in their pod characters from the type seen on the Caguán. Here the pod was rather rougher surfaced and with deeper grooves than before; the beans were all dark purple in cross section.

On the San Miguel river, in Ecuadorian territory, the explorers encountered scattered trees of *T. cacao*, known locally as "criollo del monte" (Fig. 4). As in other areas where trees were alleged to be truly wild, it was difficult to arrive at any definite conclusion as to whether or not they were indigenous. On the San Miguel the trees were encountered at some considerable distance from the river bank. The unpigmented pods borne on the trees were uniformly warty, pointed and sometimes with a definite shoulder. Every pod that had ripened was found opened by some animal, but many of the half-rotted beans left in the pod cavities were quite plump and rounded with a pale cross-section. No good seed could be found for despatch to Trinidad. Witches' broom disease was very prevalent.

Scattered cacao trees were seen on the Peruvian bank of the R. Putumayo directly opposite Puerto Leguizamo. These, too, were referred to locally as "criollo del monte." The pods on these trees were small, unpigmented, smooth surfaced and not prominently furrowed. The beans were rather pale purple in colour. No Witches' broom disease was seen in this area.

The dense forest in the vicinity of Villa Arteaga, in north-western Colombia, yielded a single interesting specimen of a cacao tree which could perhaps be a relic of an ancient cultivation. It bore the stamp of a criollo type, the two immature fruits on it being of a full red colour with the pod wall very warty; the pod stalk was delicate and slender. Budwood sent to Trinidad arrived, unfortunately, in an unusable condition; and seedlings found beneath the tree, transplanted to the rubber research station nearby, eventually all died. This tree's interest lies in its possible connection with the red-podded criollos of Venezuela.

The other cacao specimens seen by the expedition were all of genuine cultivation. Near to Villa Arteaga, mentioned in the previous paragraph, there were small abandoned cultivations of pronounced forastero types, the pods being predominantly amelonado in form, some white based and some with red pigmentation. Some seeds of this population were despatched to Trinidad. Monilia disease is very common in this area.

In the vicinity of Bucaramanga, capital of the province of Santander, was seen a small plantation of green-podded criollos, growing in full exposure to sunlight. Seed of this attractive type of cacao was sent to Trinidad. Elsewhere in this same province only very ordinary forastero types were under cultivation and these appeared to be highly susceptible to Monilia disease.

The cultivated cacaos of the Cauca valley, in the vicinity of Palmira, comprise a mixture of criollo (Fig. 5) and forastero types, the former apparently rapidly disappearing from cultivation. Some seeds and budwood from a few attractive hybrids were despatched to Trinidad.

In the valley of the lower Cauca river, in the province of Antioquia and to the north-west of Medellín, some small areas of cultivated cacao were visited. Here, again, the original criollo and near-criollo types are being superseded by inferior, but more vigorous, forastero introductions. Material from some of the locally made selections was sent to Trinidad. A few plantations to the south-west of Medellín were also visited. Here green and red podded types, with warty shells and white beans, are largely under cultivation. Seed material was sent to Trinidad. The lack of vigour of this criollo type has induced the planting of small-podded calabacillo types.

Some small and almost neglected plantings of cacao were seen along the banks of the R. Atrato, near Quibdó, capital of El Chocó province. In external pod characters the type resembles a criollo, but the cotyledons are mainly dark purple in colour. Elsewhere in the province there are signs of an old criollo-type still persisting, but now largely replaced by forastero strains. No Witches' broom disease was seen in the Cauca valley or in the Chocó, but pod rots, caused by *Phytophthora palmivora* Butl. and *Monilia roseri*, were common.

In the northern province of Magdalena the expedition visited several small areas of cacao cultivation. In the Aracataca region a small and very warty pod type was encountered, green or red in colour, with white and pale purple seeds. At Rincón Hondo, further east towards the Venezuelan border, were seen plantings of mixed forastero and a small green-podded criollo (Fig. 6). At Dibulla there are many cacao trees scattered in the forests of the northern foothills of the Santa Marta mountains, but these trees are not regarded as indigenous types. They bear pods which are small and narrowly oval, without a bottleneck, but with a sharp, short point, pale green and

inconspicuously 10-ridged, sometimes warty, but usually smooth (Fig. 7). The pod shell is thin and soft. The beans are small and white. In the same area were seen plantings of the Palmira type criollo, the seeds having been brought from there.

In the Tibú area, near the Venezuelan border in the province of Norte de Santander, some scattered trees of cacao were seen along the banks of the R. Nuevo. The pod is small, oval, green and warty, with white beans. Seeds were despatched to Trinidad. In the foothills nearby are to be found trees, not considered wild, that bear smooth red pods, rather like a sharply pointed calabacillo type (Fig. 8); the beans are purple. Nowhere in Magdalena or Norte de Santander were any signs of Witches' broom or Monilia diseases seen.

Conclusions

The explorations of the expedition, carried out in a rather restricted geographical area, have not revealed any facts in disparity with the hypothesis put forward by Cheesman (1944), and based on Pound's much more extensive travels, that the centre of origin of *Theobroma cacao* lies near the Colombian-Ecuadorian boundary on the eastern flanks of the Andes. Cheesman's hypothesis is based on Pound's report (1938) that greatest diversification of types is encountered in the area, each river there being characterised by its own central form. Certainly the cacaos seen on the San Miguel and Caguán rivers were of very different types, the former bearing rather large, rough, warty and unpigmented pods with pale coloured beans, the latter bearing small, smooth pods with dark beans inside. The finding of pale-tinted beans in the San Miguel population lends some support to the view that the white-bean criollo and purple-bean amazonian forastero had ancestrally a common origin at the hypothetical centre. The preference known historically to have been shown by the Andean Indians for white-bean cacaos could readily account for the present widespread occurrence of this type, from Central America to Colombia and Venezuela, a distribution which makes it, at the present time, a matter of some doubt whether or not all criollos can be referred to the hypothecated centre of origin mentioned above.

Cheesman, in the paper cited, states that Pound attempted to explain the similarity between certain types of cacao of unknown origin found very occasionally in the forests of Trinidad and Tobago and the type known as "criollo de la montagne," found along the upper Amazon rivers Napo and Orteguaza, by suggesting that the latter type had spread down the Orinoco and finally had reached Trinidad. This hypothesis can now be regarded as untenable because nowhere does such a "criollo de la montagne" occur on such rivers as the Inírida and Guaviare which drain to the Orinoco.

The discovery of a fully red-pigmented criollo type in the forests near Villa Arteaga, possibly a relic of an ancient cultivation, is of interest because such a type might form a link with the predominantly red podded criollos of Venezuela. The Andean foothills of north-western Colombia might well be an area from which sprang the typically green-podded Central American criollos and the predominantly red-podded Venezuelan criollos.

THEOBROMA BICOLOR H. & B. in Pl. Aequin. I. 104.

Specimens were seen only as cultivated trees on the rivers Apaporis, Caquetá, Inírida, Negro, Papurí, Putumayo and Vaupés and also in the departments of El Chocó and Valle.

The majority of trees were 6-10 m. high, but one seen in the forest of the R. Inírida was 25-30 m. high and overtopped the surrounding trees. Growth continues from below the jorquette. The branches are typically lax and whippy giving the tree a characteristic appearance. The leaves measure up to 32 cm. long by 19 cm. wide on the fan branches, but on chupons and seedlings are very much larger and cordate. The awl-shaped stipules are finely pubescent and somewhat persistent. The small cymose inflorescences are produced only in the axils of the younger leaves. The flowers generally resemble those of cacao but are of a dark red and purple colour. The fruits, measuring up to 20 cm. in length and 15 cm. in diameter, are broadly ellipsoid, prominently five-ribbed longitudinally with minor ribs and reticulations (Fig. 9).

This species although very commonly planted in Colombia—a group of about 40 trees was seen at Puerto Leguízamo—is probably not indigenous to the country. It is reported from the southerly part of the Pacific coast to be susceptible to Witches' broom disease. None of the trees seen was found infected, but this could quite possibly be due to disease escape.

Amazonian Species

THEOBROMA CALODESMIS Diels. in Notizbl. Bot. Gart. Berlin XIV. 336 (1939).

Collected frequently, the trees were seen on the rivers Apaporis, Caguán, Caquetá, Guainía, Inírida, Papunaua and Putumayo.

It is a medium-sized tree up to 15 m. high with a trunk diameter at the base of up to 30 cm. Growth continues from below the jorquette and the branching is regularly dichotomous. The old branches continuously fall off, resulting in a naked trunk crowned by the youngest jorquettes. This gives the tree a somewhat symmetric appearance in contrast to the straggling branch habit of *T. subincana* and *T. obovata*. The foliage and the branches lie almost in the horizontal plane making the crown flat-topped. The rather tough and leathery leaves, variable in size, measure up to 35 cm. long and 20 cm. wide. The stipules are small, linear-lanceolate, pubescent, and very early deciduous. The large cymose inflorescences (Fig. 10) are usually borne on the trunk, although a tree growing at 550 m. in land cleared of forest at Mocoa yielded fruit from the smaller branches as well. Each inflorescence may have as many as 400 pedicels, 100-200 flowers being open at the same time. The flowers have large, almost circular ligules and long conspicuous stamens, both a deep crimson; the calyx is persistent. The fruits, borne on long pedicels, measure up to 13 cm. long and 9 cm. wide (Fig. 12). They are bluntly pentagonal in cross-section with five shallow furrows, bluish green and not changing colour when ripe. The surface is covered with fine white hairs and is velvety to the touch; the apex is indented by a stylar pit, and the shell has a hard woody inner layer. The beans have white cotyledons and are embedded in a very sweet pale orange pulp.

First described from Ecuador, this species has a distribution similar to that of *T. subincana* and in the Caguán

and Caquetá areas it was abundant. It is not found in low-lying forest prone to flooding. Remarkably it was not seen on the rivers Vaupés, Papurí and Kuduyarí although found north of this area on the R. Inírida and south of it on the R. Apaporis. Like the other wild *Theobroma* species from south-east Colombia it is apparently absent from the west and north of the country. The flowering periods are obviously very brief in duration for of the many trees encountered only two flowering specimens were seen. Seed was obtained once—from the tree at Mocoa.

An unidentified member of the *speciosa* group to which this species belongs had previously been reported to be attacked by Witches' broom disease. Symptoms suggestive of this disease were seen on the rivers Caguán, Caquetá, Inírida and Papunaua. Both the vegetative and flowering parts of the tree are attacked. No sporophores were ever seen, but basidiomycete mycelium was found both in stem and pod tissue suspected of showing symptoms. These take the form of pronounced swellings on the smaller branches, not typical of the disease on other hosts, and reduction of the inflorescence with accompanying distortion and swelling of the pedicels and young pods.

THEOBROMA MICROCARPA Mart. in Buchn. Repert. XXXV, 24 (1830).

Only near La Pedrera on the R. Caquetá were mature trees found. A young plant at Remolino on the same river furnished material which was not typical.

It is a large tree up to 20 m. high with a trunk diameter at the base of up to 30 cm. and an extensive branch system. The three-branched jorquetting habit is not readily seen in adult trees. Growth continues from above the jorquette. The small, papery leaves measure up to 16 cm. long and 7 cm. wide. The stipules are small, acicular, pubescent, and early deciduous. The flowers, slightly smaller than those of *T. cacao*, occur only in the axils of the younger leaves. The petals are aligulate and the staminodes acicular. The fruits are ellipsoid, sometimes almost spherical, up to 9.5 cm. long and 6.5 cm. in diameter (Fig. 11). The thin, finely hairy shell has five primary and five secondary longitudinal ridges with prominent reticulations in between. Seed was not obtained for the trees were seen out of the fruiting season.

This proved to be the rarest of the four indigenous species found in south-east Colombia and it has not been reported from any other part of the country. The trees were found flowering in October, and in May another visit was paid to the area to get seed; all ripe pods had by then, however, been robbed by animals. On this latter visit the trees were found standing in several feet of moving flood water.

At La Pedrera malformations on the young fruit suggested that this species too is susceptible to Witches' broom disease, not previously reported for it.

THEOBROMA SUBINCANA Mart. in Buchn. Repert. XXXV, 23 (1830).

This species was seen throughout the Vaupés and numerous collections were made from the rivers Apaporis, Inírida, Kuduyarí, Miritiparaná, Negro, Papunaua and Piriparaná. It was also collected in Amazonas, Caquetá and Putumayo.

A tree of medium height up to 16 m. with a trunk diameter at the base of up to 25 cm., growth continues from above the jorquette. The leaves are large, sometimes up to 40 cm. long and 20 cm. wide. The stipules are narrowly lanceolate, pubescent and early deciduous. The small flowers are borne singly or in small groups on the lesser branches, never on the trunk. They have conspicuous scarlet ligules and scarlet petaloid staminodes. The fruits, up to 11.5 cm. long and 6.5 cm. in diameter, are elliptic with rather straight sides and blunt ends, pale green in colour ripening to orange (Fig. 13). The surface is smooth and covered with a soft orange-brown pubescence of stellate hairs. There is a hard woody outer layer, 1-2 mm. thick, to the shell. The seeds are embedded in a white pulp which may turn yellowish with maturity.

T. subincana is easily the most widespread and probably the most abundant *Theobroma* species in the lowland forests of south-east Colombia. It was found on flat low-lying ground above flood level and in rising country. On the Caguán and Caquetá it was scarce on the flat, very low lands immediately bordering the rivers where *T. cacao* was common. It flowers and fruits fairly readily, the flowering season being towards the latter part of the year. Growing in the open away from its natural habitat it assumes a bushy uncharacteristic appearance.

Witches' broom disease was present in nearly all the collecting areas. In some places most of the trees were infected, some very heavily. Both green and dry fan and cushion brooms, very similar to those on *T. cacao*, were found. Trees often bore numerous small, apparently parthenocarpic, pods probably indirectly infected from the cushions, but no infection of full grown pods was observed. Typical sporophores were seen at Jinogojé (Aug. 1952), in the Mitú region (Oct. 1952), on the R. Papurí (Nov. 1952) and on the R. Inírida (Feb. 1953).

THEOBROMA GRANDIFLORA (Spreng.) K. Schum. in Mart. Fl. Bras. XII, iii. (1896), 76.

Specimens were seen in gardens and man-made clearings as planted trees, few in number, on the rivers Apaporis, Caquetá, Piriparaná and Vaupés.

Only young trees were found 3-4 m. in height. Growth continues from above the jorquette. The leaves are up to 57 cm. long and 15 cm. wide, but usually appreciably smaller. The large awl-shaped stipules are stiff, glabrous and persistent. The flowers are found singly or in small groups on the smaller branches only. They are large for the genus; the petals are cream-coloured with prominent crimson ligules and the petaloid staminodes are a deep crimson (Fig. 14). No fruits were found.

This species is probably not indigenous to Colombia. None of the trees seen was attacked by Witches' broom disease, but it has been reported from Brazil as being extremely susceptible. (Pound, 1938).

THEOBROMA OBOVATA Klotzsch ex Bernoulli in Denkschr. Schw. Naturf. Ges. XXIV (1871), iii. 14.

This species was collected only from the rivers Caguán, upper and lower Caquetá and the Putumayo.

A tree, small to medium in size, it grows up to 15 m. high, but more usually 6-8 m., with a stem diameter at the base of up to 25 cm. Growth continues from above the jorquette. The thin papery leaves can measure up to 35 cm. long by 15 cm. wide, but they are usually half this size. Both surfaces of the mature leaf are almost glabrous

but the young leaves, stipules, and stem of the young flush are characteristically covered with an early caducous down of orange hairs. The rather persistent stipules are small and awl-shaped. The inflorescences are borne on the younger branches and are commonly only two-flowered. The flowers are similar to those of *T. subincana*. The fruit measure up to 6.0 cm. long and 4.5 cm. in diameter, elliptic but sometimes almost spherical, with a pronounced shoulder and a slight depression indicating the position of the stigma (Fig. 15). They are deep green in colour ripening to orange, without ridges, but the thin shell is covered with small rough papillae in between which are thinly scattered stellate hairs. The small, flat seeds are embedded in a white pulp.

In some areas this species may be as common as *T. subincana*, but it is generally less abundant and its distribution in Colombia would appear to be much more restricted since it was not found on the rivers north of the Caquetá. The two species resemble one another; *T. obovata* differing chiefly in its slenderer and slighter habit and in its smaller, rough and bottle-necked fruit. Flowering specimens were found from October right through to May and a tree on the R. Caucaýá was seen in April with many pods. Plants have been established in Trinidad.

Symptoms suggesting the presence of Witches' broom disease were found for the first time on this species near La Pedrera. One tree on the R. Caucaýá was observed with over thirty fan brooms. They can be very large, up to 40 cm. long, and profusely branched. They are not very conspicuously swollen and are slenderer than brooms on cacao. Typical symptoms were observed on inflorescences and the young fruit. No sporophores occurred but basidiomycete mycelium has since been observed in vegetative tissue showing symptoms. The disease was also recorded from the R. Caguán.

A single tree found in the forest at Remolino on the R. Caquetá suggested a hybrid origin between this species and *T. subincana*. The leaves resembled those of the latter species, but the young parts were covered with the caducous orange down typical of *T. obovata*. The fruits were up to 9.5 cm. in length and 5 cm. in diameter with a minutely verrucose surface, a well marked shoulder and a shallow stylar pit (Fig. 16). An attempt to establish plants in Trinidad from seed was not successful. The tree was infected by Witches' broom disease.

Pacific Species

THEOBROMA CAPILLIFERA Cuatr. in Notas a la Flora de Colombia, VIII, Revista de la Academia Colombiana, 6: 533-551 (1946).

This species was found in the lowland forests of the Department of El Chocó between the R. Calima and the upper R. Atrato where it is not common. The tree is 15-20 m. in height and the diameter at the base of the trunk is about 20 cms. New growth of the stem takes place from below the jorquette as in the case of *T. calodesmis* which it resembles in habit and the regularly dichotomous fan branches. The rather leathery leaves are variable in shape, being generally ovate but varying in width at the base. Their size is very variable reaching 28 cm. long by 12 cm. wide. The inflorescences are borne on the trunk in many-flowered cymes with long peduncles (Fig. 17). The flowers are crimson, the ligules being broad and oval and the staminodes lanceolate.

Only dry fruits were seen which had five blunt ridges and measured up to 25 cm. long by 8 cm. in diameter (Fig. 18). This species differs from *T. calodesmis* mainly in the size and shape of the fruits.

THEOBROMA GILERI Cuatr. in Rev. Int. de Bot. Appl. et d'Agric. Trop. 562-565 (1953).

This species was collected only from northern Antioquia in the vicinity of Villa Arteaga where it is fairly common in the plains and foothills to the east.

Trees of this species attain a height of about 12 m. New growth continues from above the jorquette, but several shoots often grow from below so that many trees lose the characteristic appearance of the species. The leaves measure about 19 cm. by 10 cm.; they are almost glabrous and are papery in texture. The flowers are borne in cushions on the trunk and often singly on older wood on the branches. The flowers are small and resemble those of *T. microcarpa* with awl-shaped staminodes and aligulate petals. The staminodes and petals are crimson in colour. The fruits are roundish measuring up to 9 cm. long by 7 cm. in diameter, having five prominent ridges, five lesser ridges and transverse reticulations as in *T. bicolor* (Fig. 19). The fruits contain a few large seeds embedded in a white pulp. Seeds of this species were sent to Trinidad but arrived in a decomposed condition. The fungus *Monilia roreri* Ciferri was found infecting fruit of this species.

THEOBROMA NEMORALE Cuatr. in Notas a la Flora de Colombia, XII, Revista de la Academia Colombiana, 8: 464-488 (1952).

This species occurs in the Pacific coastal area near the R. Calima and lower R. San Juan. This area has a low altitude and is slightly hilly.

The tree is 8-10 m. in height. The diameter at the base of the trunk is about 20 cm. New growth of the stem arises above the jorquette. The leaves are medium-sized measuring up to 29 cm. by 12 cm. The flowers are borne on the smaller branches singly or in pairs. The petals are yellow with broadly spatulate ligules. The spatulate staminodes, which are crimson in colour, are bent outwards at right angles above the petals. The small fruits measure up to 10 cm. long by 5.5 cm. in diameter and are orange in colour when mature (Fig. 20). The surface of the woody shell is pubescent and is not ridged, but there is a definite constriction below the peduncle. The pulp of the mature fruit is yellowish-white. Plants have been established in Trinidad from seed of one collection.

Two sterile collections were made on the R. San Juan which have been considered by Prof. Cuatrecasas to be forms of this species.

THEOBROMA CIRMOLINAE Cuatr. in Notas a la Flora de Colombia, VI, Cali, Departamento del Valle del Cauca, República de Colombia, p. 5 (1944).

This apparently rare and endemic species was collected in the valley of the R. Digua or Anchicayá in the Departamento del Valle del Cauca. The trees seen grow at an altitude of 800-1,000 m., the highest altitude for any of the wild *Theobromas* seen. These trees were growing on level areas on the mountains overlooking the river.

It is a fairly large tree 12-15 m. in height and the base of the trunk measures 30-35 cm. in diameter. The young stem shoots arise above the jorquettes. The leaves

on the chupons are suborbicular. Those on the branches are very large, measuring up to 57 cm. long by 28 cm. wide and are markedly unequal at the base, the veins being fairly prominent. The stipules are lanceolate and longitudinally ribbed. The large cymose inflorescences (Fig. 21) are borne on the trunk and main branches. The yellow flowers are similar in size to those of *T. angustifolia* but differ in the shorter, almost orbicular, ligule. The fruits are long and narrow, about 30 cm. by 11 cm. in diameter (Fig. 22). The thickly pubescent surface is dark brown. The older fruits have five blunt ridges separated by broad shallow furrows. The pulp is pale yellow in colour and possesses a strong aroma. Several plants have been established from seed sent to Trinidad.

THEOBROMA SP.

Two trees of this species were seen at Villa Arteaga, Antioquia, on low hills. One of these trees was mature and was 12 m. in height with a trunk 20 cm. in diameter at the base. New growth takes place from above the jorquette. The large leaves measure 54 cm. long by 21 cm. wide and the strongly reticulated upper surface is somewhat bullate. The veins are prominent on the lower surface. The large (27 mm. by 9 mm.) and prominent stipules are somewhat cordate at the base and taper towards the apex. The surface of the stipules bears many longitudinal ribs. The flowers are borne in large inflorescences on the trunk and in leaf axils on the older branches. They are similar in appearance to the flowers of *T. cirmolinae* and *T. angustifolia* but differ from them in the absence of red pigmentation at the base of the stamens and staminodes. The ligules are suborbicular and the spatulate staminodes are more or less erect. The one fruit observed was ovate in outline, measuring 18 cm. long by 10 cm. in diameter and contained 55 flattened seeds, a very large number for the size of the pod. The shell is woody with a smooth and heavily pubescent surface. Seeds were sent to Trinidad but growth did not continue after emergence of the radicles.

THEOBROMA SP. (possibly new).

One tree was seen in El Chocó near the confluence of the R. Andágueda and R. Atrato in slightly elevated land. This tree was about 12 m. in height and new growth of the stem continued above the jorquette. The young vegetative buds are orange in colour. The coarse and large leaves measure up to 41 cm. long by 17 cm. wide, the upper surface being strongly reticulate-bullate and the veins are extremely prominent on the lower surface. The midrib on the upper surface is conspicuously wavy. The broad, leafy, persistent stipules measure 25 mm. long by 15 mm. wide, and are similar in appearance to those of the two previous species. The tree was sterile but the flowers appeared to be borne on the branches. This species seems to be related to the preceding species by the similar leaves and stipules.

THEOBROMA SIMIARUM Donnell Smith in Botanical Gazette 25 : 145 (1898).

(See also : Standley, P. C., Flora of Costa Rica, Part II, Fieldiana : Botany, 18 : 689, 1937).

Found in the Chocó in the R. Calima area and on low hills in the vicinity of Villa Arteaga. This species has been reported from Costa Rica and these collections are the first made in Colombia. In spite of its wide area of distribution it appears to be rare.

The tree reaches 12-15 m. in height. The growth of the stem continues above the jorquette. The leaves are medium-sized, up to 31 cm. by 17 cm., but on the chupons they may be larger. The upper surface of the leaves is slightly reticulate-bullate and the veins are prominent on the lower surface. The lanceolate persistent stipules measure more than 14 mm. by 4 mm. The specimens seen were flowerless, but one tree bore, on branches, two dry fruits which measured 16 cm. by 11 cm. and 20 cm. by 10 cm. (Fig. 23). The woody shell is not ridged and the surface is pubescent. No seeds were obtained.

Diseases

Two important pathogens of cacao restricted to parts of tropical South America have been briefly mentioned, where applicable, in the sections on *Theobroma* species. They are *Marasmius perniciosus* Stahel and *Monilia roreri* Ciferri and some general comments on them may be made.

In no part of Colombia, on any *Theobroma* species, were these two diseases found in the same locality. Simultaneous occurrence is said to occur only in south-west Nariño, but the expedition had no opportunity to verify this. They occur together nearby over the border in Ecuador. Elsewhere in Colombia the two diseases appear to be almost complementary in their distribution. Witches' broom disease is found in the south-eastern lowlands, probably not further north than the second parallel, and in a part of Nariño. *Monilia* disease occurs in the western and north-western parts of the country. Unexpectedly, it was not seen in the provinces of Magdalena or Norte de Santander, although it has been reported from the R. Catatumbo area in Venezuela, north-east of Tibú. *Marasmius perniciosus* was not found above an altitude of 400 m., and only in areas with a probable annual rainfall in excess of 80 inches. *Monilia roreri* was found near sea level to 1,000 m. in places with rainfall varying from 40 to 400 inches per annum. The most probable reasons for the absence of Witches' broom disease in the upper parts of the rather dry valleys of the Cauca and Magdalena rivers are a limiting low rainfall and geographical isolation.

Previously *Marasmius perniciosus* had been reported attacking, besides *Theobroma cacao*, *T. bicolor*, *T. grandiflora*, *T. subincana* (Fig. 24) and a species of the *speciosa* group (Pound, 1938). Symptoms of the disease have now been seen on *T. calodesmis* (Figs. 25 and 26), *T. microcarpa* and *T. obovata* (Figs. 27, 28 and 29). A collection of *T. glauca* Karsten in the Herbario Nacional Colombiano from the mountains of the Macarena which lie off the east Andean flank in central Colombia shows evidence of infection by the disease. The symptoms on the fruit are similar to those on the closely related species *T. calodesmis*. It is probable, therefore, that all the wild species which occur in the area where the disease is present are susceptible to it. Since it is not known to occur in the west, where different species of *Theobroma* occur, we do not yet know whether these may also prove to be susceptible.

Monilia roreri is much more restricted in its distribution. In Colombia it is widespread in the Cauca and Magdalena river valleys and also occurs in the low-lying country on the Pacific side. Previously it had been reported infecting *T. bicolor* and *Herrania balaensis* besides *T. cacao* (Fig. 30 ; Stell, 1933). One additional host was recorded ; *T. gileri* at Villa Arteaga (Fig. 31). The disease has also been reported from Ecuador, Peru and eastern Venezuela. It

is easily recognised in the field and is stated to cause very serious losses. Our knowledge of all aspects of it is very slight. Possibly the earliest record of the fungus is cited by Parsons (1949), where it is reported to have attacked the cultivated cacao near the town of Antioquia in 1851.

Of the other diseases of cacao the ubiquitous *Phytophthora palmivora* Butl. was observed wherever the cultivated crop occurred. Very severe canker, caused by this fungus, was seen at Palmira on criollo trees. One of the minor root diseases caused by *Rosellinia* sp. occurred commonly in very old criollo fields at Puerto Tejada. No leaf symptoms similar to those caused by cacao virus in Trinidad were ever found.

Herrania Goudot

Our account of this genus in Colombia is based on the monograph (in the press) by Richard Evans Schultes. We are much indebted to Dr. Schultes for an advance copy of his monograph and for his help in determining our specimens, all of which he has examined critically. *Herrania* is a genus of the family Sterculiaceae, closely allied to *Theobroma*, differing mainly in its virtually unbranching habit of growth, in its compound palmate leaves and in possessing non-convoluted cotyledons. The flowers, too, are much larger than those of most *Theobroma* species and usually have very long filamentous ligules to the petals (Fig. 35). It is suspected also that the fat of the beans differs, at any rate in some species, from cacao butter in having a lower melting point. All species are primarily lower storey forest trees, but a number act like weeds and propagate rapidly in agricultural clearings. With the exception of *H. purpurea*, which is found also in Panama, Costa Rica and Nicaragua, all species are confined to the forests of South America in the countries of Brazil, Peru, Ecuador, Colombia, Venezuela and the Guianas. Of the 17 species treated by Schultes all except two have now been found in Colombia, where they have been most intensively collected, and of these we have seen nine. The genus is apparently never attacked by the Witches' broom disease of cacao.

HERRANIA BREVILIGULATA R. E. Schultes in *Caldasia* 1, p. 21 (1942).

Collected once only from near Mocoa on the upper R. Putumayo. The tree, growing in a clearing, was some 3 m. high and, unfortunately, bore no ripe fruit. Immature fruits were collected for the first time for this species (Fig. 32), but seed could not be sent to Trinidad.

HERRANIA CAMARGOANA R. E. Schultes in Bot. Mus. Leaflet. Harvard Univ. 14, 120 (1950).

Collected for the first time in Colombia from near San Felipe on the R. Negro and again near Inambú on the R. Vaupés on both the Colombian and Brazilian banks of the river.

A tall-growing robust species with a trunk up to 15 cm. in diameter at the base. The ripe fruits, described elsewhere as red or blood-red in colour, with characteristic spiny projections (Fig. 33), in our material were yellow. The older leaves usually have nine leaflets. Seed sent to Trinidad has germinated satisfactorily.

HERRANIA CUATRECASANA García-Barriga in *Caldasia* 2, p. 58 (1941).

Found only near Mocoa and at Monclar on the upper R. Putumayo and on the R. San Miguel in Ecuadorean

territory. The trees, about 3 m. tall, are very common in secondary bush near Mocoa, and the rather large pods have a prominent tapering apex, sparsely pubescent (Fig. 34). Seeds were sent to Trinidad.

HERRANIA KOFANORUM R. E. Schultes in Bot. Mus. Leaflet. Harvard Univ. 14, 126 (1950).

Only known from the upper Putumayo valley of Ecuador and Colombia, this species was found once at Puerto Leguizamo on the upper R. Putumayo. The trees, 4-5 m. tall, unfortunately were all sterile.

HERRANIA NITIDA (Poeppig) R. E. Schultes in *Caldasia* 2, p. 17 (1943). *Abroma nitida* (Poeppig) Nov. gen. ac Sp. Pl. 3, 73 (1845).

According to Schultes this is the most widespread species of the genus extending from the eastern slopes of the Andes throughout the entire Amazon basin. In Colombia we have specimens from many rivers (Aporis, Caquetá, Paca, Inírida, Papunaua, Putumayo and Caguán) in the provinces of Vaupés, Amazonas, Caquetá and Putumayo.

H. nitida is a small slender tree seldom exceeding 3 or 4 m. in height readily recognisable by the brittle irritant hairs on the pods (Figs. 35 and 36). Several collections of seed were sent to Trinidad and successfully germinated.

HERRANIA NYCTERODENDRON R. E. Schultes in *Caldasia* 2, p. 22 (1943).

Only known previously from near Leticia in the Trapecio Amazónico of Colombia and from the R. Putumayo in Peru, this species was found near La Pedrera on the lower Caquetá, in several localities on the upper Caquetá, on the R. Caguán and R. Caucaýá and on both the Colombian and Peruvian banks of the upper Putumayo.

A fairly robust species reaching 7 to 8 m., *H. nycterodendron* can be recognised by the soft indument of velvety hairs on the fruits (Fig. 37).

Seed sent to Trinidad germinated satisfactorily.

HERRANIA PULCHERRIMA Goudot var. *pacifica* R. E. Schultes in Bot. Mus. Leaflet. Harvard Univ. 14, 131 (1950).

This species is known only from the mountainous regions of Colombia. We have one specimen from Lloró in the Chocó province. It was also seen on the R. Calima. It appears to be fairly widely distributed in the upper valley of the R. Atrato and R. San Juan, but never common. Many healthy trees were seen in clearings, but all were sterile at the time when this area was visited, in August.

HERRANIA PURPUREA (Pittier) R. E. Schultes in *Caldasia* 2, p. 333 (1944). *Theobroma purpureum* Pittier in Fedde Rep. Sp. 13, 319 (1914).

This is the only species known from Central America, where it has been collected fairly frequently in Costa Rica and Panama and once in Nicaragua. Its distribution includes north-western Colombia and we have several specimens from Villa Arteaga in the province of Antioquia. It is fairly common on flat low-lying land, but was also seen in several places on the hills to the east. The trees are some 5 m. tall and the flowers peculiar in that they do not open fully and have petals with rather short (30 mm.) ligules. Seed was sent to Trinidad (Fig. 38).

HERRANIA UMBRATICA R. E. Schultes in *Caldasia* 2, p. 263, (1943).

This species is known only from north-eastern Colombia in the vicinity of Santander. We have collections from

three rivers, Oru, Tibu, and Nuevo in Norte de Santander province, and from Capitancitos, Santander province, at 650 m. altitude.

Very common in the drainage system of the R. Catatumbo, it is especially abundant on flat land along river banks which are often inundated to a depth of 18 inches. It is less common in the foothills of the Andes. A tall tree, reaching about 7 m., it is a very prolific bearer, one tree having 44 ripe fruits. The fruits ripen yellow and have numerous irritant hairs (Fig. 39). Flowers, found for the first time on wild trees, do not open fully and have short ligules. Two collections of seed sent to Trinidad from Tibu have survived, but a collection from Capitancitos did not germinate.

Entomological Section*

The primary object of the entomological work of the Anglo-Colombian Cocoa Collecting Expedition was to make a survey of the mealybugs, the capsids, their parasites and predators, in the areas of Colombia which were being searched for new types and varieties of species of *Theobroma*. Opportunity was taken to collect other insects associated with species of *Theobroma* and the closely related genus, *Herrania*. The identification of the collections is not yet complete and, therefore, this report can only refer to the general incidence of the groups of insects concerned. It is proposed to publish a list of the species found when the determinations are available.

This survey was undertaken as a preliminary step in the examination of the possibility of introducing into West Africa parasites from South America, to further the work at the West African Cacao Research Institute in the biological control of the insects associated with the two major scourges of cacao in that region, namely, "Swollen Shoot" and "Capsid damage." Cacao Swollen Shoot Virus is transmitted by numerous species of Pseudococcids (Anon., 1947, 1950). The four species of Miridae (Capsidae) which attack cacao in the Gold Coast are *Sahlbergella singularis* Hagl., *Distantiella theobroma* (Dist.), *Helopeltis bergrothi* Reut., and *Bryocoropsis laticollis* Schum., but only *S. singularis* and *D. theobroma* are of major economic importance (Anon., 1947).

The period from the middle of August, 1952, to the latter part of December, 1952, was spent with the main party of the expedition in the virgin forests of south-eastern Colombia. The following month was spent collecting parasitised mealybugs in the two main areas of cacao cultivation in the inhabited part of that country. Mealybugs and mirids were searched for on all classes of vegetation in the forest, although species of *Theobroma* and *Herrania* received particular attention, and large numbers of these were felled and closely examined. All mealybugs encountered were placed with pieces of the host-plant in breeding tubes, and were subsequently observed for indications of parasitism. Specimens from each group, or colony, of mealybugs were preserved in spirit as were any emergent parasites. The preserved material was later given to the Commonwealth Institute of Entomology for identification.

It was proposed, when facilities were available, to send parasitised material to Trinidad in order to try to establish cultures of the parasites on local mealybugs. Many con-

signments were dispatched from the cacao growing areas, but owing to the irregularity and infrequency of communications it was extremely difficult to send living material from the forests of south-eastern Colombia.

The first base in south-eastern Colombia was on the R. Apaporis, which, for the greater part of its length, separates the provinces of Vaupés and Amazonas. Five weeks were spent in the forest along this river and its tributaries, the Piriparaná, Comyacá, and the Ricapuyá. This period coincided with the latter part of the "wet" season, and at the time much of the forest was flooded. Only eight colonies of mealybugs were found. Six of these occurred on the foliage and young shoots of *Theobroma subincana* Mart. and, with one exception, were attended by ants and were under carton-coverings. The largest colony contained 27 adult females. A small ant-attended colony under a carton-covering was found on an isolated tree of *Theobroma grandiflora* (Spreng.) K. Schum. on the Ricapuyá. The eighth colony, which consisted of five adult females, was found in an ants' nest inside an enlarged leaf petiole of an unidentified leguminous sapling. Collections of individual female mealybugs were obtained from the foliage of *T. subincana*, and other unidentified forest trees. Hymenopterous parasites and some Cecidomyids with predacious larvæ were reared from one of the colonies found on *T. subincana*. A similar dipterous species was also reared from the only unattended mealybug colony found on *T. subincana*. No parasites or predators were obtained from the other collections and no mirids were found.

In the middle of September the second base was made in the Amazonas at La Pedrera on the R. Caquetá, from which the explorations continued for some four weeks. In the forest, on the banks above and below La Pedrera and on an island in the river, scattered trees of *Theobroma cacao* were found. These were all very old and very tall, and were not obviously cultivated. Flowers and cherelles were present on the trees, but there were very few pods. Many of these trees were cut down and searched leaf by leaf for mealybugs; less than half the trees examined were found to be infested, and the number of mealybugs per tree was low. The average population on infested trees numbered 14 and the maximum number found on a single tree was 47. All the mealybugs encountered were in the canopy, and consisted of individual females, apparently unattended, on the upper and lower surfaces of the leaves. No colonies were seen, and no mealybugs were found on pods. Individual females were also collected on *T. subincana*, *T. grandiflora*, *Herrania nitida* (Poeppig) R. E. Schultes, a cultivated guava (*Psidium guajava* L.), and on unidentified Moraceous and Monimiaceous seedlings. A small mealybug colony was found on *Theobroma microcarpa* Mart., and on a *Heliconia* sp. It is thought that at least five species of mealybugs are represented in these collections. Hymenopterous parasites or hyperparasites emerged from about 2% of the mealybugs found on *T. cacao*. Some of the mealybugs collected on the guava tree were parasitised, as were the mealybugs in the small colony from the *Heliconia* sp. Several adult Coccinellids were reared from larvæ feeding on the mealybug colony on *T. microcarpa*. No mirids were found and no signs of their attack were seen on the *T. cacao*.

In October the expedition returned to the province of Vaupés, where a base was established at Mitú. During the following two months journeys were made up the main tributaries, and along the whole length of the lower reaches

* By D. J. Taylor, now Entomologist at the West African Cacao Research Institute, Tafo, Gold Coast.

of the R. Vaupés, and also its confluent at the Brazilian border, the R. Papurí. The "dry" season started in November, and was said to continue until the end of February. There is a fairly numerous indigenous population along the R. Vaupés, and the consequent food-crop cultivations and secondary bush proved to be interesting collecting grounds. Over 70 collections of mealybugs were made in this region, from eight of which parasites were reared. Several mirids were collected, though none was parasitised. Single trees of *T. cacao* were found near existing or abandoned settlements on the banks of the R. Vaupés; and along the R. Papurí several small areas of abandoned *T. cacao* were seen. Mealybugs were only rarely found on the scattered trees, and only one large colony was found in the derelict cacao. All the mealybugs found occurred on stems or leaves. Many trees of *T. subincana* were cut down and examined. Mealybugs were found on about a quarter of the trees, but apart from two large colonies they occurred singly or in very small colonies, scattered in the foliage. Both large colonies and several of the small ones were ant-attended and under carton-coverings. Three of the species found in this region occurred on both *T. subincana* and *T. cacao*. On the lower R. Vaupés two large ant-attended colonies were found on the fruit of *Herrania camargoana* R. E. Schultes. Large colonies were also found on cultivated sugar cane at a Mission Station, and many collections were made from pineapples found growing near Indian settlements. Interesting collections of mealybugs were obtained from ants' nests inside the stems of certain plants of the families Leguminosæ, Melastomaceæ, and Rubiaceæ. Although hymenopterous parasites emerged from some of the mealybugs in the two large colonies and from several of the small colonies on *T. subincana*, the degree of parasitism was very low. However, over 40% of the adults in one of the colonies found on *H. camargoana* were parasitised; no parasites were obtained from a similar colony found on a tree of the same species less than half a mile away. From the only large colony found on *T. cacao* adult Cecidomyids, with predacious larvæ, were reared. Hymenopterous parasites were bred from some of the pineapple mealybugs but rather surprisingly none was obtained from the large colonies on sugar cane. The opportunity occurred, and was taken, of sending a consignment of parasitised material out of this area. However, the package was delayed in transit and all the material was dead on arrival in Trinidad.

After leaving the forests of the south-eastern provinces of Amazonas and Vaupés, it was decided to spend a month collecting parasites in two of the main areas of cacao cultivation of Colombia. The largest cacao-producing region is along the R. Cauca in the provinces of Valle and Cauca, and is responsible for more than half the national production of 10,000 tons. This region is 3,000-3,500 feet above sea level. The other extensive cacao-growing region visited was between the towns of San Jerónimo and Santa Fé de Antioquia in the province of Antioquia, where the cacao is growing at an altitude of over 2,000 feet. Although at the times of the visits the greater part of the main crop had been harvested, many colonies of mealybugs were found on the stems and the remaining maturing pods of cacao. Four species of mealybugs were found common to both regions. As was to be expected the degree of parasitism was higher than had hitherto been encountered in the forests. In some colonies 20% of the adults were "mummified," though the mean rate was rather less than 5%. Predaceous Cecidomyid and Coccinellid larvæ

were frequently obtained. Two consignments of parasitised mealybugs from Antioquia, and eight consignments of parasitised material and predators from the Cauca Valley, were sent to Trinidad.

A species of *Monalonia* (probably *M. dissimulatum* Dist.) is an important pest of cacao in Antioquia. A large number of nymphs and adults of this mirid was collected and maintained in breeding cages, but none showed signs of parasitism. The writer was informed that a worker at the Faculty of Agriculture of the University in Medellín had found no parasites during the course of a year's intensive study of this pest. Localised outbreaks of this mirid have occurred in the Cauca Valley, but it is not widespread in that region. This is largely due to the rigid control measures which are taken when outbreaks are reported.

The material sent to Trinidad was handled by Prof. T. W. Kirkpatrick of the Imperial College of Tropical Agriculture, and Mr. F. D. Bennett of the West Indies Substation of the Commonwealth Institute of Biological Control. With one exception, the consignments of parasitised material arrived in Trinidad within a week of being dispatched, and from them many hundreds of hymenopterous parasites, in good condition, were obtained. They included at least six species of Encyrtids. The parasites were introduced to colonies of mealybugs on sprouted potato tubers in pill-boxes. The species of mealybugs used were *Planococcus citri* (Risso), *Pseudococcus adonidum* (L.), *Ferrisia virgata* (Ckll.), *Dysmicoccus* sp. near *brevipes* (Ckll.), and *Phenacoccus* sp. Although sexual behaviour was noted amongst some of the introduced parasites, none of the species became established on the Trinidad mealybugs.

While the aim of the work was primarily an exploratory survey of the forest regions, it was rather disappointing that the parasites introduced from the Colombian cacao areas failed to breed through on the mealybugs in Trinidad. The reason for this may become clearer when the parasites and their original hosts have been determined. The results of this survey will give much information on the distribution and relative abundance of Coccids under the conditions of equilibrium which obtain in the forests of south-eastern Colombia where the influence of man has been little felt. It is doubtful, however, whether this region could, at present, be considered a source of parasites for biological control work. The major obstacle lies in the lack of a regular means of transport from the forests to the normal centres of communication in Colombia. The only way into, and out of, the forest regions is by air, but the services are infrequent, irregular and uncertain, due largely to circumstances beyond the control of the operators. It is questionable, also, whether parasitised material would survive the journey from the forests to Bogotá, as the planes, which are unheated, have to climb to 15,000 feet during the last hour of the flight.

Acknowledgments

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arrival in Trinidad. The advice and assistance of numerous officials of the Colombian Ministry of Agriculture, and of that of the entomological staffs of the Universities in Medellin and Palmira is gratefully acknowledged. The writer also wishes to thank his botanical

colleagues, Colombian and British, on the expedition for their co-operation and assistance in identifying host-plants. Mr. A. Pickles, Deputy Director of Cacao Research, W.A.C.R.I., is thanked for reading through the draft of this report, and for his helpful suggestions.

APPENDIX

The following table summarises the number of collections of mealybugs made in each of the three areas visited in south-eastern Colombia, together with a list of host-plants on which they were found, and the number of collections from which parasites or predators were obtained.

	No. of collections of mealybugs	Host-plants	No. of mealybug collections from which parasites or predators were obtained
R. Apaporis	17	<i>T. subincana</i> <i>T. grandiflora</i> Unidentified leguminous sapling	2
R. Caquetá	25	<i>T. subincana</i> <i>T. grandiflora</i> <i>H. nitida</i> <i>Psidium guajava</i>	5
R. Vaupés	74	<i>T. subincana</i> <i>T. cacao</i> <i>T. bicolor</i> <i>H. camargoana</i> Pine-apples Sugar cane Unidentified plants of Leguminosae, Melastomaceae and Rubiaceae	8

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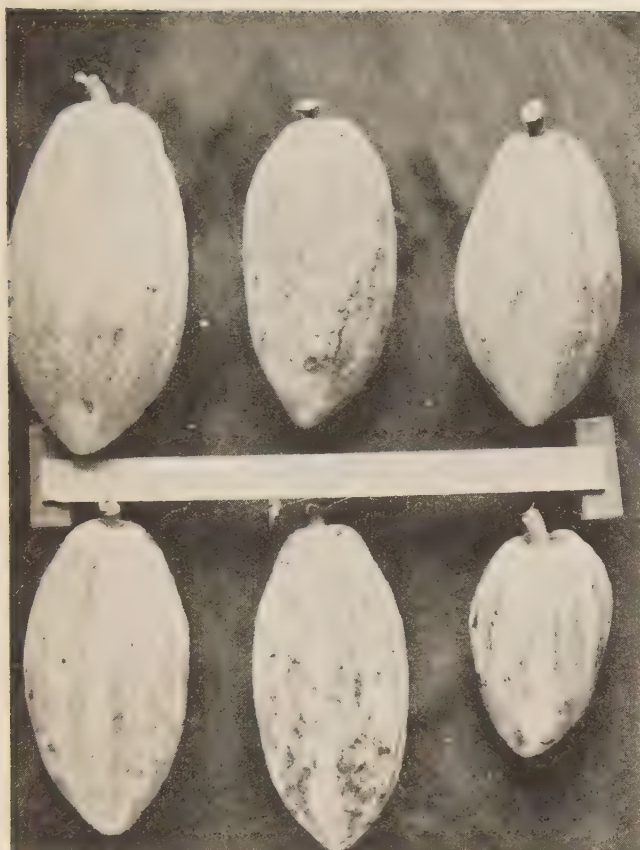


FIGURE 1

T. cacao from La Pedrera; a poor yellow-podded Amazonian Forastero.

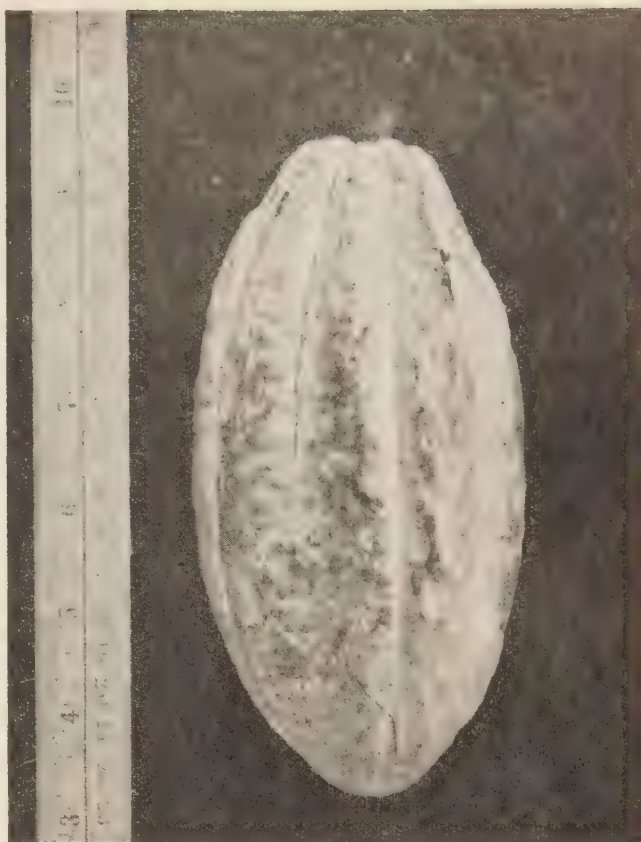


FIGURE 2

T. cacao from R. Papuri; another yellow-podded Amazonian Forastero.



FIGURE 3

T. cacao from R. Caguan; Amazonian Forastero, yellow with traces of red pigmentation.

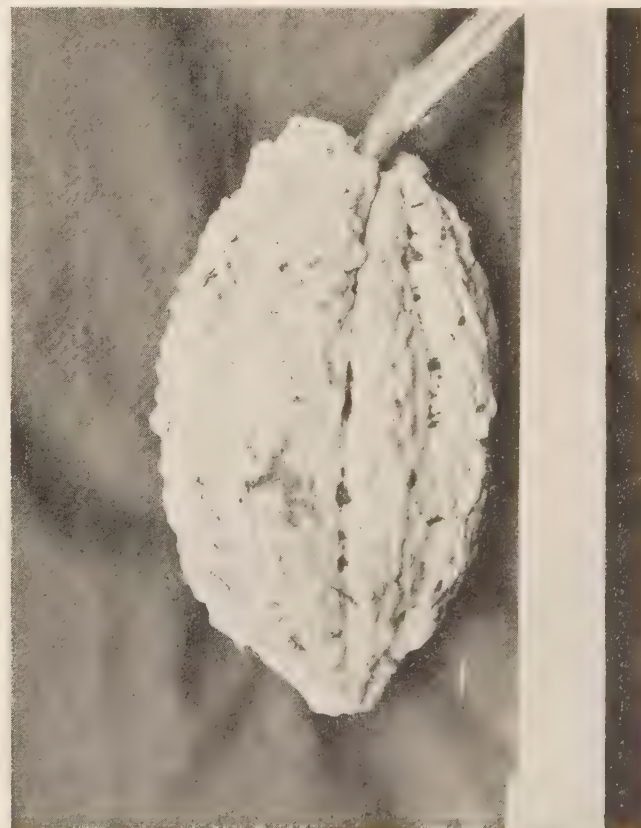


FIGURE 4

T. cacao from R. San Miguel; "Criollo del monte."



FIGURE 5
T. cacao. Red-podded Criollo from Cauca Valley, near Palmira.



FIGURE 6
T. cacao. Small green-podded Criollo from Rincon Hondo.



FIGURE 7
T. cacao. Green-podded cacao from Dibulla.



FIGURE 8
T. cacao. Red-podded Calabacillo from Tibu.

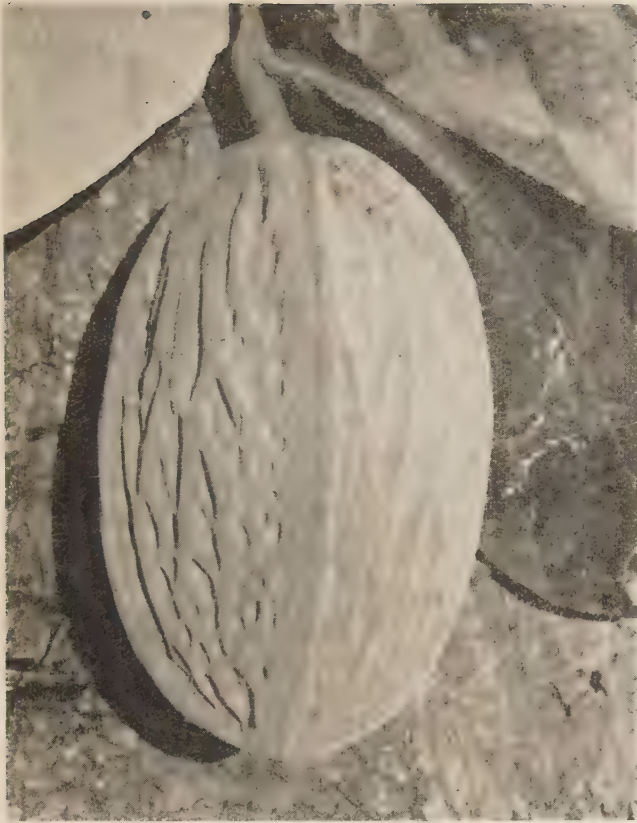


FIGURE 9
T. bicolor from La Pedrera.



FIGURE 10
T. calodesmis from R. Caguan Many-flowered inflorescences.



FIGURE 11
T. microcarpa from La Pedrera. Dry pods, about one-third natural size.

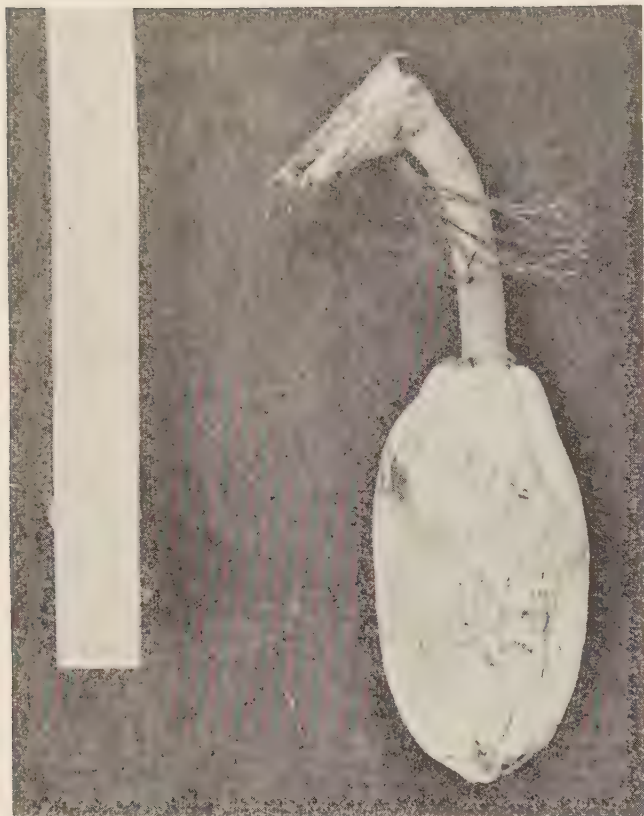


FIGURE 12
T. calodesmis from R. Caguan. Nearly mature pod.



FIGURE 13
T. subincana from R. Caucaya near P. Leguizamo.



FIGURE 14
T. grandiflora from La Pedrera Flower (slightly reduced).



FIGURE 15
T. obovata from R. Caucaya. Nearly mature fruit.

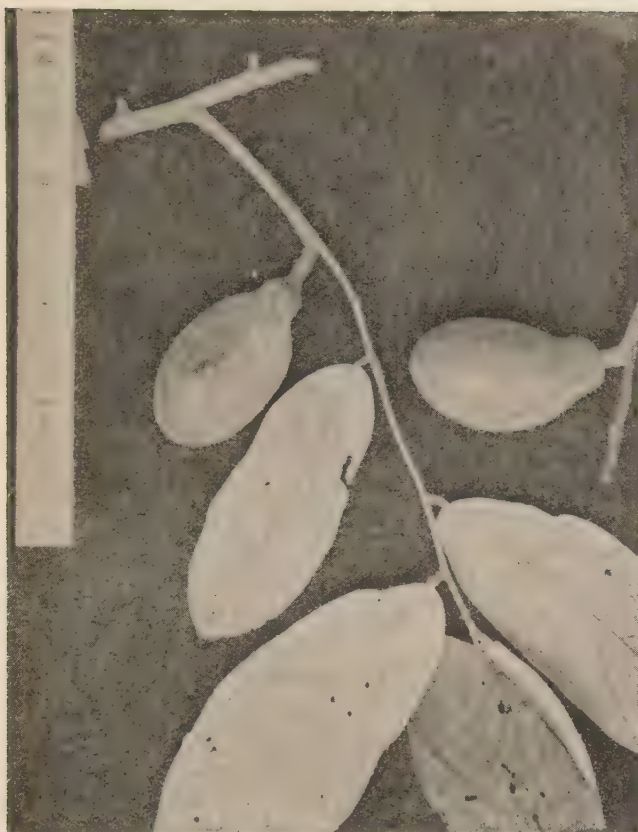


FIGURE 16
T. obovata x *T. subincana* from Remolino, R. Caqueta. Nearly mature fruit.



FIGURE 17
T. capillifera from El Choco. Many-flowered inflorescence.



FIGURE 18.
T. capillifera from El Choco. Dry fruits.



FIGURE 19
T. gileri from Villa Arteaga.

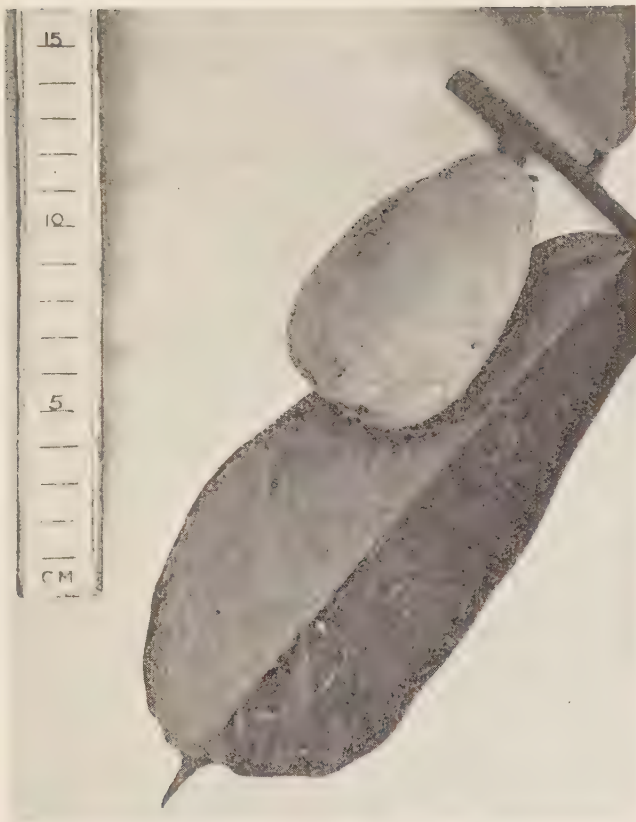


FIGURE 20
T. memorale from E. Choco.



FIGURE 21
T. cirmolinae from R. Digua. Many-flowered inflorescence.



FIGURE 22
T. cirmolinae from R. Digua. Mature fruits.



FIGURE 23
T. simiarum from R. Calima. Mature fruit.



FIGURE 24
Witches' broom disease on *T. subincana* from Yavarate.



FIGURE 25
Suspected witches' broom disease on *T. calodesmis* from R. Inirida.



FIGURE 26
Young fruit of *T. calodesmis* from R. Caguan attacked by witches' broom disease.



FIGURE 27
Large vegetative witches' broom on *T. obovata* from R. Cauca.

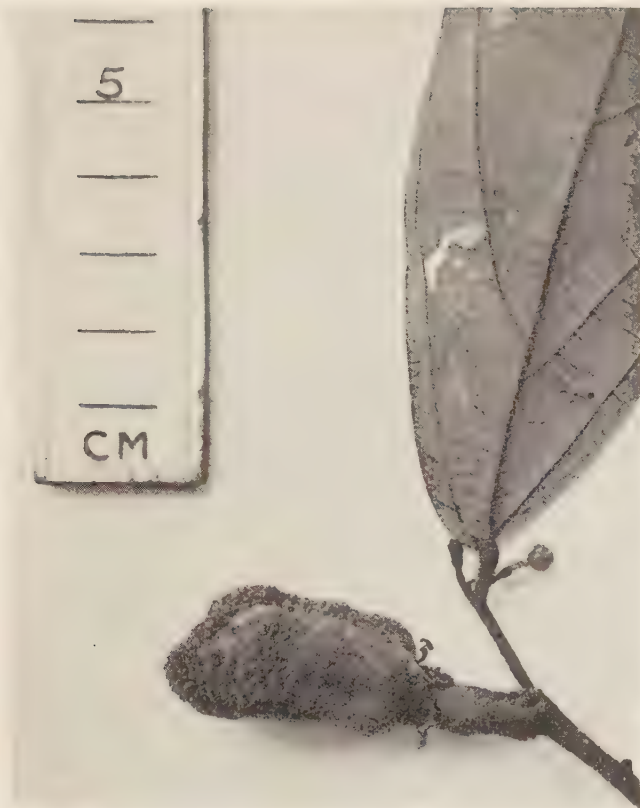


FIGURE 28
Young fruit of *T. obovata* from R. Caucaya attacked by witches' broom disease.



FIGURE 29
Cushion of *T. obovata* from R. Caucaya attacked by witches' broom disease.

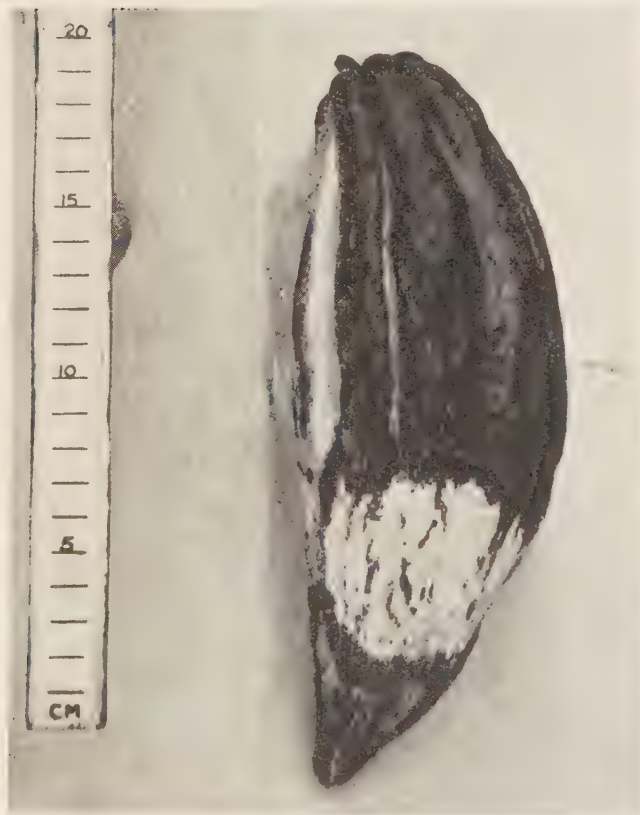


FIGURE 30
Pod of *T. cacao* from Cauca valley attacked by Monilia disease.



FIGURE 31
Pods of *T. gileri* from Villa Arteaga attacked by Monilia disease.



FIGURE 32
Immature pod of *H. breviligulata* from Mocoa.



FIGURE 33
Fruit and cushion of *H. camargoana* from R. Vaupes.



FIGURE 34
Nearly mature pods of *H. cuatrecasana* from Mocoa.



FIGURE 35
Flowers of *H. nitida* from R. Caqueta. Slightly reduced.



FIGURE 36
Pods of *H. nitida* from R. San Miguel.

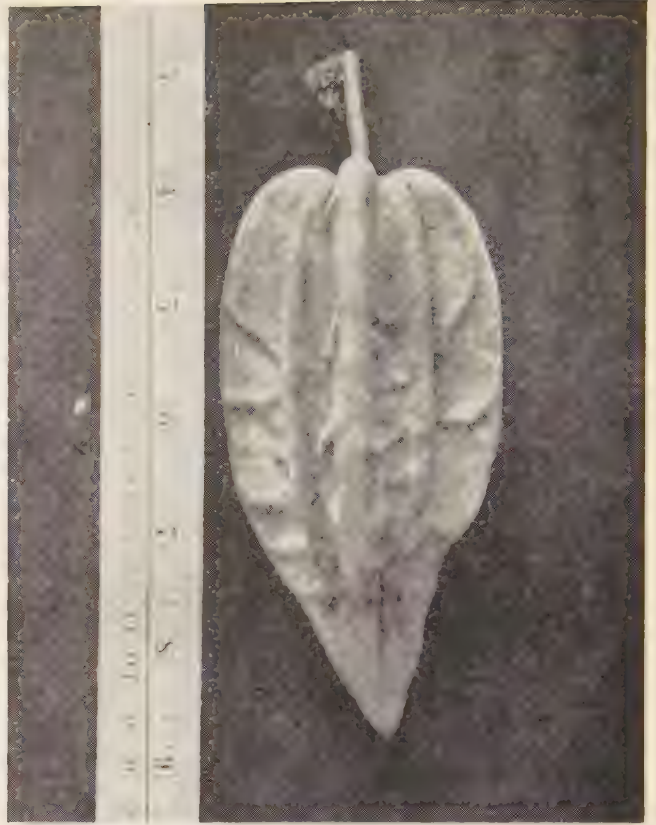


FIGURE 37
Pod of *H. nycterodendron* from La Pedrera.



FIGURE 38
Pod of *H. purpurea* from Villa Arteaga.



FIGURE 39
Pods of *H. umbratica* from near Tibu.



Map of the Republic of Colombia showing the areas explored by the expedition.

A Shade and Fertiliser Experiment with Cacao. III

by

D. B. Murray

PRELIMINARY accounts of this experiment have been given by Evans and Murray (1953) and Murray (1953). The treatments compare the effect of five light intensities ranging from 100% to 15% of full sunlight, together with eight fertiliser treatments, on the early growth of three clones, ICS 1, 60 and 95. The experiment was planted in 1950.

General Management and Observations

Fertilisers were applied in the requisite treatments during 1953 at the following rates in lbs./tree.

	28/1/53	18/5/53	12/10/53	Total
Ammonium sulphate (N)	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{2}$
Superphosphate (P) ...	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{4}$
Sulphate of potash (K) ...	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{4}$

The rate has been stepped up 50% on the previous year and the first application was made at the end of the rainy season, the second at the beginning of the rains and the third during a short break in the rainy season.

For their age the best trees have made extremely good growth and treatment differences have become more pronounced. At low light intensities the plants develop a few long lax branches, growth is poor and fertiliser differences are not apparent. As light intensity increases the plants are more vigorous, but at 75% and 100% of full light, growth is very dependent on fertiliser treatment. Without additional nitrogen, the plants are stunted, with small, yellowish (nitrogen deficient) leaves. In treatments with nitrogen, the trees are extremely vigorous and have grown faster during the year than the best trees at 50% light which, previously, had made the best growth. Growth at high light intensities results in a considerable development of lateral branches and a bush type of tree with a closed canopy.

Yields

During the 1952-53 crop year, the trees were harvested approximately monthly and the numbers of pods and weight of wet beans per tree recorded. These figures are given in Appendix I. Yields range from nothing to 34 pods per tree, this latter tree giving 3,800 gm. wet cacao. Using a conversion of wet to dry cacao of 40%, this is the equivalent of 3.3 lb. dry cacao, an extremely high figure for a tree in its third year in the field.

The analysis of variance has been done on yields expressed as numbers of pods. In regard to the main effects of light intensity, fertiliser and clone, differences in each case proved significant at $P=0.01$. The comparison between clones being largely determined by genetic factors, differences due to the physiological effects of light and fertiliser treatment will be considered first and for this purpose means for the three clones have been used in preparing Table I.

TABLE I

Mean number of pods per tree from four trees of each of three clones in relation to light intensity and fertiliser treatment.

Fertilisers	Light Intensity (% full sunlight)					Means
	15%	25%	50%	75%	100%	
Control ...	1.67	3.58	6.00	2.67	3.08	3.40
N ...	2.33	6.41	10.42	8.17	10.75	7.61
P ...	1.33	3.83	8.00	4.67	1.67	3.90
K ...	1.50	4.33	7.25	7.08	2.25	4.48
NP ...	2.83	4.17	10.42	12.92	6.67	7.40
NK ...	3.75	4.42	8.50	12.75	12.00	8.28
PK ...	2.42	4.33	7.92	8.67	6.42	5.95
NPK ...	4.25	6.25	11.00	12.50	12.17	9.23
Means ...	2.51	4.67	8.69	8.68	6.78	

S.E. for differences in light intensity means ± 0.96 .

S.E. for differences in fertiliser means ± 1.10 .

From this table it is clear that at low light intensities of 15% and 25% of full light, yields are low irrespective of fertiliser application. Mean yield increases up to 50% of full light but thereafter the effect of light intensity is strongly modified by the nature of the fertiliser application. In the controls, P, K and PK treatments, i.e., all those not receiving N, the peak yield is given at about 50% light intensity and there is a marked decline in yield at 75% and 100% light intensities. Where N has been applied, however, yields at 50% and higher light intensities are greater and the peak yields have also advanced to a higher light intensity. The response to potash is also conditioned by light intensity and these interactions of N and K with light intensity are shown in Table II.

TABLE II

Mean number of pods per tree from four trees of each of three clones in relation to light intensity and (a) N fertiliser, (b) K fertiliser.

(a)

		Light Intensity (% full sunlight)				
		15%	25%	50%	75%	100%
With N	...	3.29	5.31	10.08	11.58	10.40
Without N	...	1.73	4.02	7.29	5.77	3.35
Means	...	2.51	4.67	8.69	8.68	6.78
Differences	...	1.56	1.29	2.79	5.81	7.05

(b)

		Light Intensity (% full sunlight)				
		15%	25%	50%	75%	100%
With K	...	2.98	4.83	8.67	10.25	8.21
Without K	...	2.04	4.50	8.71	7.10	5.54
Means	...	2.51	4.67	8.69	8.68	6.78
Differences	...	0.94	0.33	-0.04	3.15	2.67

S.E. for differences in light intensity means ± 0.55 .

S.E. for differences in fertiliser means ± 0.96 .

S.E. for differences in light means at same fertiliser level ± 1.27 .

S.E. for differences in fertiliser means at same light level ± 1.23 .

The effect of the application of N was progressively greater with increase in light intensity resulting in a three-fold increase in yield in full light over plants not receiving N. At the same time plants not receiving N but shaded to 50% light intensity gave more than twice the yield of corresponding plants in full light, i.e., the reduction in light intensity was equivalent to an application of N. The effect of additional K was not significant at light intensities of 50% and lower, but above this point additional K also resulted in an increase in yield over plants not receiving K. And, again, reduction of light intensity from full light to 50% resulted in yields which were greater than for plants receiving K but growing in full light.

The interaction of P with light intensity was not significant. The NK effect was small and non-significant indicating that N and K in the presence of each other are slightly less effective than the sum of the separate effects of N and K.

As the prime consideration in this experiment lies in the determination of the basic physiological interactions of the cacao tree to its environment, no detailed comparison of the various light and fertiliser treatments will be made. In any case, fertiliser applications were arbitrary so that the results do not necessarily indicate the optimum conditions for growing young cacao in the field. What the results do indicate are the basic factors that must be considered in deciding on such a field programme of shade and manuring.

To simplify the picture, consideration will, therefore, centre on the comparison between the control plants and the plants receiving NPK. That is, the comparison of plants growing at low and high (but not necessarily optimum) levels of nutrition.

This nutritional interaction with light intensity is illustrated in Fig. 1 where smoothed curves have been drawn for the relation of yield and light intensity for the control and NPK plants. These curves show the increasing light intensity needed for highest yields as the nutrient level is increased, and also the greater yield increment with increasing light for the same fertiliser application.

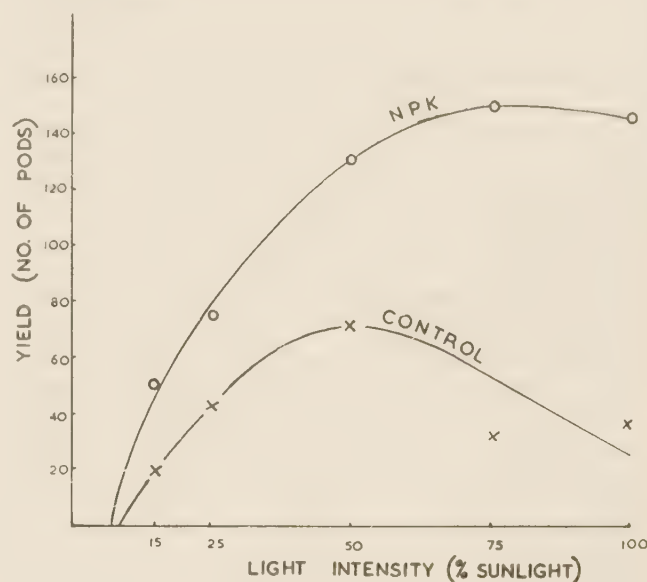


FIGURE 1

The relationship of yield (number of pods for totals of 12 trees) to light intensity for control and NPK plants.

An attempt has been made to express this relation between yield in number of pods and light intensity on a mathematical basis and Fig. 2 shows the results of plotting yields against the logarithm of light intensity (sunlight=100) for the control and NPK plants.

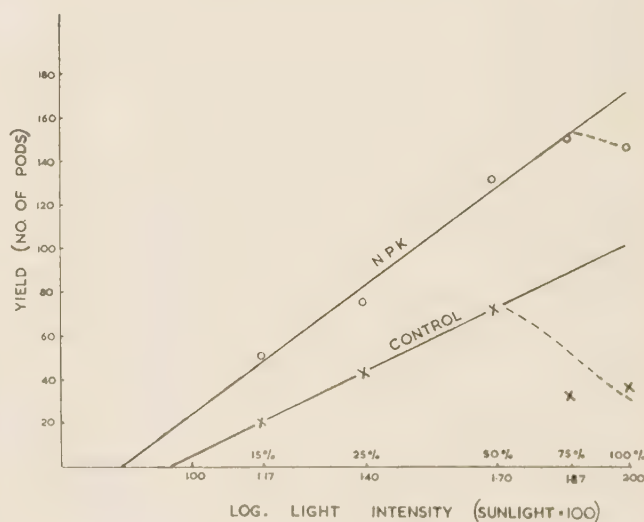


FIGURE 2

The relationship of yield to the logarithm of light intensity.

For the controls, a very close linear relation exists between the yields and log. light intensity between 15% and 50% of full light. Above 50% light, however, this

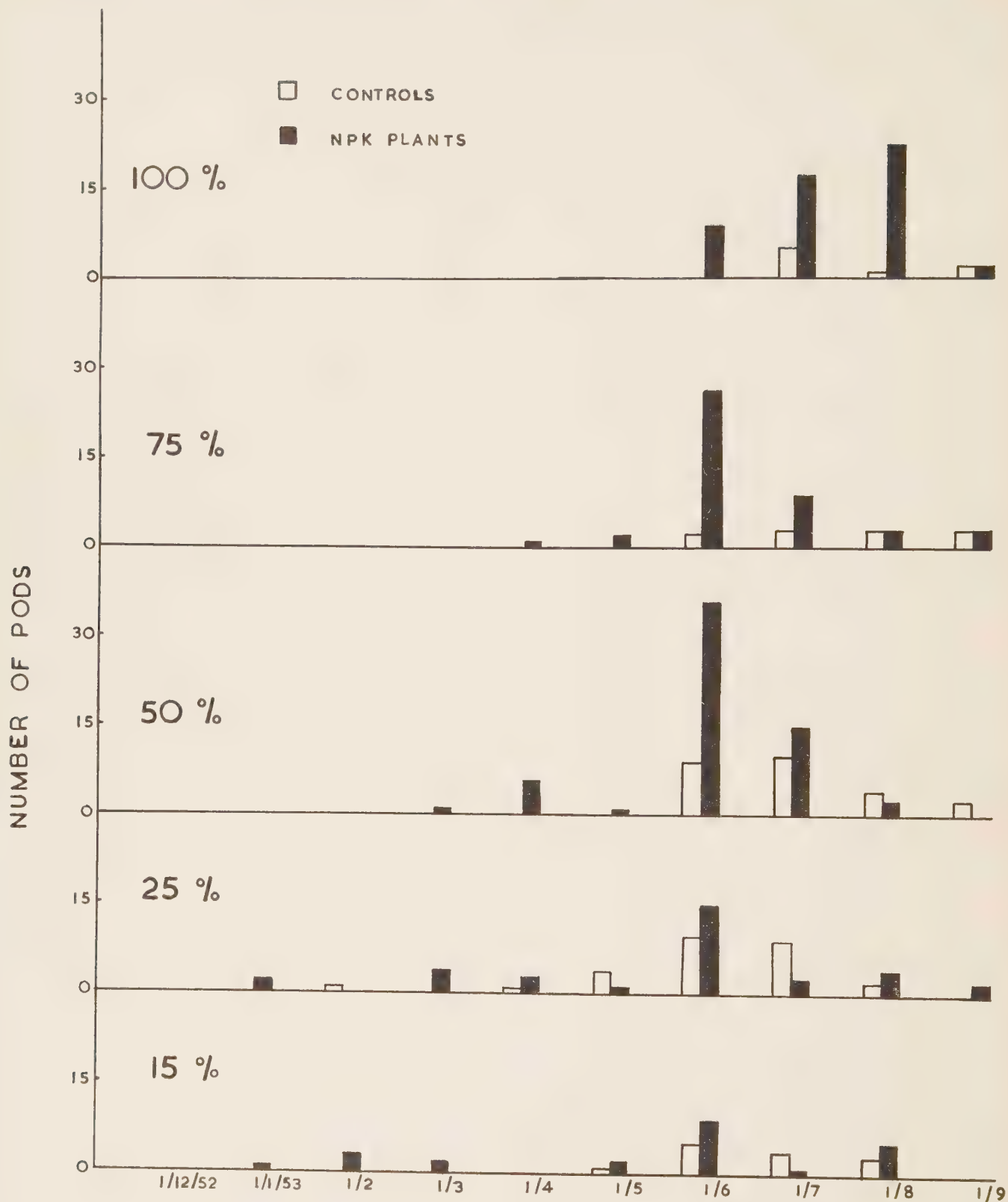


FIGURE 3
The number of pods (totals for 4 ICS 95 trees) harvested from controls and NPK plants at each harvesting date.

relation breaks down, yields at 75% and 100% being clearly unrelated to the linear relation. With the NPK plants, however, the linearity is maintained up to 75% light intensity and only above this intensity does the yield depart from the linear relation. Furthermore, the departure from linearity is less marked than in the case of the control plants.

If Y = number of pods and X = light intensity (sunlight = 100) then the regression equations for the two lines are :—

$$\text{Controls } Y = 97.7 \log X - 93.7 \\ \text{Sig. at } P = 0.03$$

$$\text{NPK } Y = 148.2 \log X - 124.7 \\ \text{Sig. at } P = 0.02$$

The hypothesis is, therefore, advanced that the yield of young cacao is linearly related to the logarithm of light intensity but that this relation is conditioned by nutrient availability. When nutrient availability is low the linearity breaks down at a lower light intensity than when the nutrient supply is high.

Extrapolation of the fitted lines to cut the light intensity axis gives the light intensity at which no pods would have been produced. For the control plants this "yield extinction point" occurs at 9% light intensity and for the NPK plants at 7% light intensity. It is of interest to note that Blackman (1951) has shown that the compensation point, i.e., the point at which the net assimilation rate balances the respiration rate and growth does not occur, lies between 6% and 9% for a number of temperate species.

Extrapolation of the regression line for the NPK plants to 100% light intensity indicates the highest potential yield and it is tempting to suggest that with higher or more frequent NPK applications linearity might have been maintained up to full sunlight.

The relationship has also been tested for yields expressed as weights of wet beans and similar results found, though with different values for the regression equations.

Differences between clones introduces the factor of weight of beans per pod. Although ICS 95 has produced the largest number of pods at all light intensities, these pods are smaller and have contained a lower weight of wet cacao per pod than either ICS 1 or 60. A full analysis of bean weight must, however, involve such additional considerations as maturity of pod at harvest, relation of harvesting date to season, etc., and will not be embarked upon.

Development of the Crop

The number of pods produced at each harvesting date for the ICS 95 control and NPK plants is shown in Fig. 3. The normal main crop in Trinidad is produced in December-January, but it is clear that most of this crop has developed during the second crop period, May-July. This is a not uncommon feature of the early bearing of cuttings.

It will be noted, further, that at low light intensities cropping is spread over a far wider period as compared with cropping at high light intensities. At low light intensities a steady trickle of pods is produced and peak harvests are not pronounced. At 50% light intensity, the harvesting period starts later, is shorter, and a pronounced peak harvest occurs at the end of May. In full

light the harvesting period is even more compressed and the maximum crop is given at the end of July.

As regards the effect of fertilisers : in general, the NPK plants have come into bearing earlier than the controls and the increasing effect on yield of the manurial treatment as light intensity increases is obvious.

These yield figures can be related back to the course of cherelle production. Starting in November, 1952, weekly counts were made of the number of healthy cherelles larger than 5 cm., and the number physiologically wilted since the previous count. These wilted cherelles were removed at each count. It was only practicable to make these records on one clone, ICS 95, in the control and NPK treatments at each light intensity. Furthermore, the arbitrary figure of 5 cm., corresponding to an age from pollination of 40 days, was adopted as the effort required in recording every cherelle from setting would have been excessive.

This data has been used in preparing Fig. 4, where, for clarity, only one cherelle count in each month is shown. Also included, on a reduced scale, is the data of Fig. 3, i.e., the number of ripe pods harvested in the week prior to the cherelle counting date. These pods harvested will have first appeared in the cherelle count four months previously.

The course of cherelle production and wilting foreshadows the pattern of harvesting. At low light intensities cherelles are being produced over a wide period of time whereas at high light intensities cherelle production appears with a rush.

The seasonal intensity of wilting varies with the treatments but only total wilting over the cropping period is shown in Table IV. For the arithmetical expression of cherelle wilt, the concept of potential crop is used, i.e., the crop that would have resulted if all cherelles had matured.

TABLE IV
Cherelle wilt in relation to potential crop

Treatment	Wilted cherelles larger than 5 cm.	Actual yield in pods	Potential crop	Wilt % potential crop
15% Control	65	13	78	83.5
15% NPK	145	29	174	83.5
25% Control	188	27	215	87.5
25% NPK	186	33	219	85.0
50% Control	188	25	213	88.4
50% NPK	384	61	445	86.0
75% Control	81	11	92	88.4
75% NPK	223	43	270	80.0
100% Control	32	8	40	80.0
100% NPK	312	50	362	85.5

In spite of the wide range in potential crop the percentage wilting does not show great variation and the table shows clearly how necessary it is to relate cherelle wilt to final crop. The lowest wilting percentage, controls in full light, is actually associated with the smallest crop.

In general the effect of fertilising is to reduce cherelle wilt slightly, but this reduction in wilting is not responsible for the bigger crop of the fertilised trees. This is mainly due to the production of a larger number of cherelles that achieve a length of 5 cm. It would be necessary to know

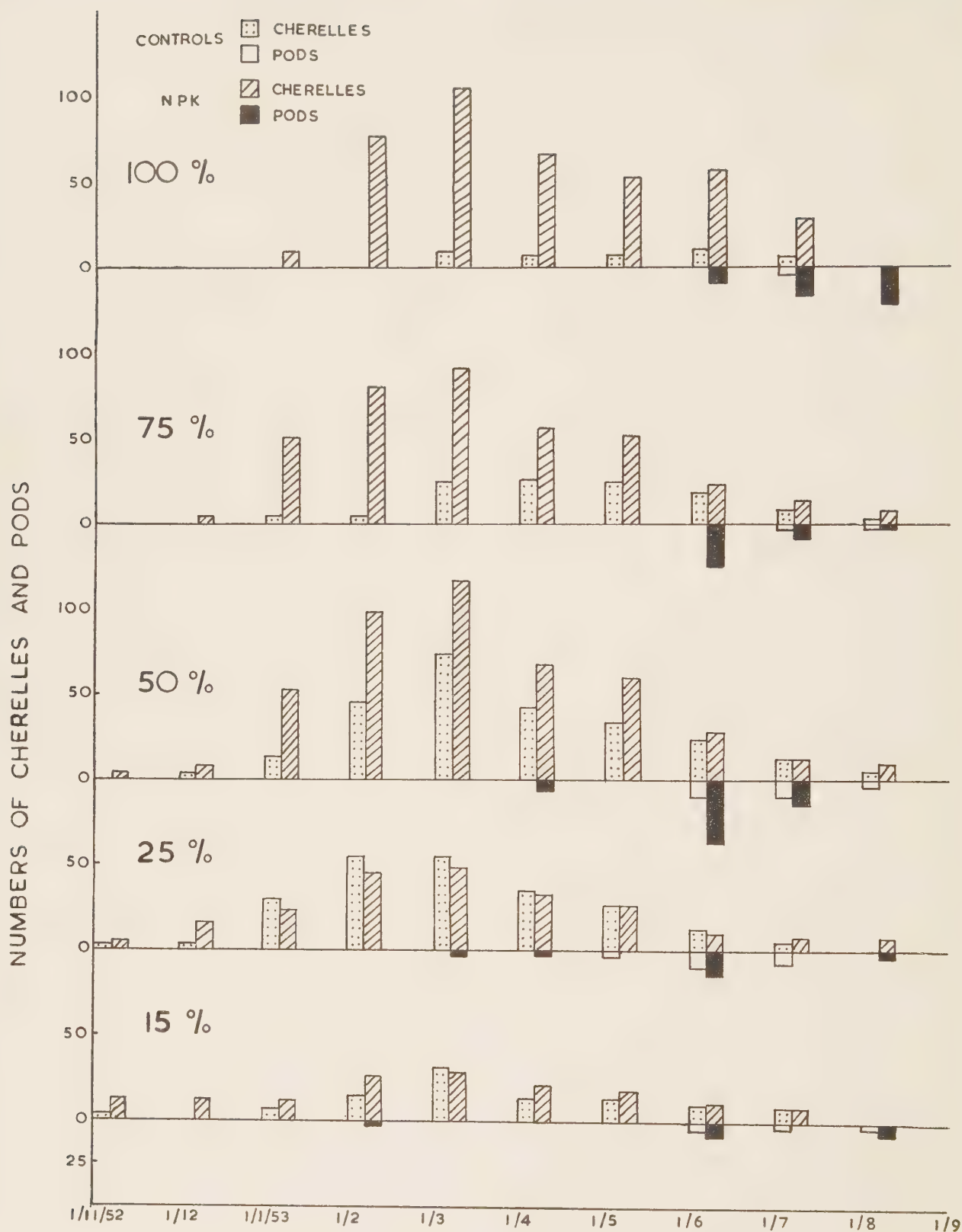


FIGURE 4
The number of cherelles larger than 5 cm. (totals for 4 ICS 95 trees) at monthly intervals and number of ripe pods resulting.

the relative figures for setting and wilting in cherelles less than 5 cm. long to complete the picture. It does, however, fit the generally accepted theory of cherelle wilt being associated with nutrient competition.

The results at 100% light appear anomalous in that the control plants have shown a lower percentage wilting than the fertilised trees. In view of the small numbers concerned in this instance this percentage figure must be less reliable.

Discussion

The demonstration of a logarithmic relation between yield and light intensity, which relation is conditioned by nutrient supply, provides a working picture of the interrelation of these factors in cacao, but any theoretical consideration of this relationship would be most difficult. The existence of a similar logarithmic relation between net assimilation rate and light intensity has been shown by Blackman and Wilson (1951) for a number of temperate annuals, but the relation of yield to net assimilation rate is quite unknown.

Blackman found that increased nutrient supply increased net assimilation rate only at the higher light intensities. His regression lines for control and NPK plants of net assimilation rate with log. light do, in fact, very closely resemble the regression lines of yields in Fig. 2. The leaf area ratio was increased proportionately at all light levels. He concludes, therefore, that a high nutrient level will be coupled with a greater light requirement for optimum growth. If yield is a function of the growth rate, then a similar relation appears for cacao, i.e., with a higher nutrient level optimum yield occurs at a greater light intensity.

Another aspect must be examined. The majority of studies of the effects of light intensity have been done on plants of such an age and size that individual leaves are all growing at much the same light intensity, i.e., self-shading is not important. In the present experiment, however, this is not the case. At high light intensities, the plants receiving NPK have grown much faster than the control plants and have a far greater leaf area. As a result self-shading is appreciable and the average incident light per unit area of leaf is much lower in the NPK plants than in the controls. It may, therefore, be said that the NPK plants nominally growing at a high light intensity are self-shading to the extent of reducing the average light intensity per unit area of leaf to a much lower level than for the control at the same light intensity. The analysis of such an effect would be extremely difficult. This factor must, however, be responsible for the more rapid growth now of the NPK plants in full light as compared with those growing at 50% light, reversing the results of the first two years' growth.

It may even be questioned whether the plants growing at the extreme ranges of light intensity and nutrient supply are of comparable physiological age. The results here given must, therefore, be considered as the integration over their entire growth of the factor of light intensity on plants submitted to different nutrient supplies. The regression equations will be unique not only to the general environment of this experiment but also to the particular period of the experiment.

It would be premature, therefore, to apply these relations *in toto* to mature cacao, but the general physiological

principles must apply. The lack of response to fertilisers in many early fertiliser trials may well have been associated with heavy shading. At low levels of light the response to fertilisers in this experiment has been much less than at high levels. This is particularly marked in the case of nitrogenous fertilising.

Again, in Grenada, it has been found that under a system of intensive cultural and manurial treatments high yields can be secured with little or no shade. Similar attempts in Trinidad in recent years to grow cacao without permanent shade have usually led to poor results. This must be associated with soils of a lower nutrient status, and the buffering effect of shade cannot be dispensed with until this has been remedied.

In the establishment of cacao in a new area it would be a safer policy to use shade trees in the beginning and then to experiment with the reduction of shade to varying extents. As soon as the cacao showed signs of reduced cropping, shade removal should cease or the effect of additional fertilisers investigated. It would then be necessary to decide whether it was more economic to secure a lower level of yield under shade or a higher level of yield with less or no shade and the use of manures.

The manipulation of shade in the field is by no means easy. Pruning is in general impracticable and reduction in the stand of trees means that part of the area is over-exposed and the remainder too heavily shaded. The ideal would be to use different shade trees with canopies of varying thickness. A light shade would be given by trees with a thin feathery foliage, heavier shade by trees with a thicker canopy.

These interactions are undoubtedly an enormous complication in the agronomy of the crop. Fertiliser trials can mean little without specifying light intensities and to include two or three light intensity treatments in a $3 \times 3 \times 3$ factorial trial would result in a most unwieldy experiment. One approach to this problem may lie in leaf analysis. It has been shown, Murray (1953), how markedly the mineral nutrition of the leaf is affected by light intensity and nutrient supply, but it has not yet been possible to deduce any definite relations in regard to yield.

Acknowledgment

The writer's thanks are due to Mr. F. W. Cope, Senior Plant Breeder, for the statistical analysis of this experiment.

Summary

(1) An analysis has been made of the yields up to date of an experiment in which the interactions of light intensity and fertiliser application are being investigated.

(2) Highly significant differences in yield have resulted from differences in light intensity, fertiliser application and clones and in some of their interactions. The effect of additional nitrogen increases markedly with increase in light intensity. A less marked effect is shown by additional potash.

(3) The hypothesis is advanced that the yield of young cacao is linearly related to the logarithm of light intensity but that this relation is conditioned by nutrient availability. When nutrient availability is low the linearity breaks down at a lower light intensity than when the nutrient supply is high.

(4) Increase in light intensity reduces the spread of the crop and delays the peak harvest. It has little effect on percentage cherelle wilt.

(5) The difficulties involved in a theoretical interpretation of the results are discussed and also the importance of the nutrition—light intensity interaction in the agronomy of the crop. On soils with low levels of available nutrients,

permanent shade would appear essential to maintain the trees in a reasonable state of health. Yields, however, will be low. On more fertile soils, shade can be reduced, the condition of the trees will not suffer and yields will be higher. The use of shade on soils of high fertility should be not only unnecessary but would be deleterious to heavy cropping.

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APPENDIX I
Yield in number of pods
(Totals for 4 trees)

15%										75%											
ICS	I	Con.	N	P	K	NP	NK	PK	NPK	Totals	ICS	I	15	38	25	14	42	54	37	51	276
	60	0	8	5	0	2	10	8	17	50		60	6	14	14	26	60	39	30	56	245
	95	7	4	1	6	8	6	10	5	47		95	11	46	17	45	53	61	37	43	313
		13	16	10	12	24	29	11	29	144			32	98	56	85	155	154	104	150	834
Totals		20	28	16	18	34	45	29	51	241											

25%										100%											
ICS	I	9	14	13	14	14	7	26	28	125	ICS	I	21	43	11	4	31	40	36	44	230
	60	7	15	17	13	8	8	8	14	90		60	8	5	1	19	11	50	16	52	162
	95	27	48	16	25	28	38	18	33	233		95	8	81	8	4	38	54	25	50	268
		43	77	46	52	50	53	52	75	448			37	129	20	27	80	144	77	146	660

50%																				
ICS	I	28	43	24	22	42	48	34	39	280										
	60	19	28	46	26	46	18	27	32	242										
	95	25	54	26	39	37	36	34	61	312										
		72	125	96	87	125	102	95	132	834										

Yields as weight of wet beans (gms.)
(Totals for 4 trees)

15%									
ICS	1	Con.	N	P	K	NP	NK	PK	NPK
	60	0	1,115	615	0	225	1,490	970	2,000
	95	985	680	250	1,035	1,340	770	800	665
		1,640	1,940	1,120	1,450	2,645	3,105	1,320	3,090
		2,625	3,735	1,985	2,485	4,210	5,365	3,090	5,755

25%									
ICS	1	Con.	N	P	K	NP	NK	PK	NPK
	60	1,165	2,340	2,265	2,370	2,045	915	4,005	3,590
	95	1,140	2,015	1,895	2,155	1,765	1,470	1,510	2,235
		2,680	4,505	2,455	2,825	2,810	4,230	2,395	4,175
		4,985	8,860	6,615	7,350	6,620	6,615	7,910	10,000

50%									
ICS	1	Con.	N	P	K	NP	NK	PK	NPK
	60	4,375	5,970	3,780	3,165	6,150	7,845	4,705	5,990
	95	3,305	4,435	6,445	4,060	6,580	2,835	4,190	4,140
		2,955	5,485	3,220	4,670	3,710	4,080	4,010	6,200
		10,635	15,890	13,445	11,895	16,440	14,760	12,905	16,330

75%									
ICS	1	Con.	N	P	K	NP	NK	PK	NPK
	60	2,665	5,375	3,695	2,180	5,660	7,450	4,590	5,890
	95	890	2,020	2,500	4,010	7,285	5,230	5,245	8,455
		1,405	4,595	1,565	5,750	4,825	6,140	4,905	4,500
		4,950	11,990	7,760	11,940	17,770	18,820	14,340	18,845

100%									
ICS	1	Con.	N	P	K	NP	NK	PK	NPK
	60	2,500	4,910	1,415	435	3,455	4,370	4,520	5,950
	95	1,350	620	115	2,070	1,855	6,980	2,300	7,220
		1,340	6,870	750	375	3,720	5,510	3,000	4,980
		5,190	12,400	2,280	2,880	9,030	16,860	9,820	18,150

Some Physical Aspects of the Cacao Shade Experiment

by

G. W. Smith

SOON after the cacao shade experiment was started measurements of some physical characteristics of the soil were made. Three aspects were considered, namely, soil moisture, soil temperature and the effect of gravel lenses whose presence in the soil profile was suspected. This paper is an attempt to summarise the results obtained.

Soil Temperature

Soil thermometers of the weekly recording type were installed on 19th February, 1951, one in the 100% light unmulched plot and one in the 100% light mulched plot. The latter was moved to the 15% light unmulched plot on 2nd November, 1951, after obtaining records for almost nine months. It has remained in this plot ever since. The 100% light unmulched plot thermometer has remained in place since the start of recordings.

Before discussing the results obtained, it is relevant to consider the best way of expressing the mean weekly temperature. There are several methods by which the required value may be extracted from the charts. One method is to take the average of the weekly extreme maximum and the weekly extreme minimum. This is a very crude way of expressing the average. It might be for instance, that on six days of the week the day temperatures remain lower than usual because of rain. (Rain has a profound influence on the shape of the curves.) The seventh day, however, might perhaps have no rain, and, on that day, the maximum temperature would be considerably higher than on the other days. Rain, however, does not appear to affect greatly the minimum temperatures. Consequently, a mean of the maximum and the minimum temperatures will give a much higher weekly mean than the true one.

A second method is to add together maximum and minimum temperatures for each of the seven days, and divide their sum by 14. This gives a value which is much closer to the required mean, but it does not take into account the fact that, for most of the day, the temperature may be relatively very high, with only a short period of low values, and *vice versa*.

A better method for finding the true mean would consist of calculating the mean of a large number of readings taken every few minutes. It is quite impracticable for this to be done manually, but the recording thermometer may serve the intended purpose.

Suppose that a trace is obtained as shown in Fig 1. Over a very small period of time, dt , the temperature may

be considered constant. Suppose that, in the total time, T , there are n such small periods, in which the temperatures are $x_1, x_2, \dots, x_n$. The arithmetical mean of these (i.e., the true mean temperature over the period of Time, T) will be :

$$M = \frac{x_1 + x_2 + \dots + x_n}{n}$$

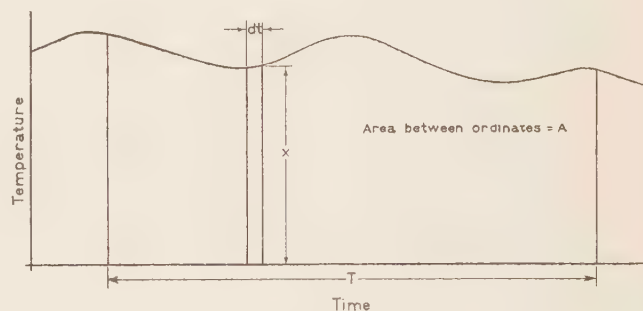


FIGURE 1

The area of the figure bounded by the trace, the two ordinates marking the beginning and end of the period, and the abscissa is :

$$\begin{aligned} A &= x_1 dt + x_2 dt + \dots + x_n dt \\ &= (x_1 + x_2 + \dots + x_n) dt \\ &= M \cdot n \cdot dt \\ \therefore M &= \frac{A}{n \cdot dt} \end{aligned}$$

Now there are n small periods of time dt in the total time T , i.e. :

$$\begin{aligned} T &= n \cdot dt \\ \therefore M &= \frac{A}{T} \end{aligned}$$

The total area, A , may be very easily measured by a planimeter (in arbitrary units if more convenient). It will represent a quantity temperature multiplied by time. It is necessary to determine how many planimeter units are equivalent to a given number of temperature-time units. For this purpose, the area X , in planimeter units, which represents a certain number of °F.-day units is determined by tracing with the planimeter the area formed by, say, the ordinates bounding the beginning of the first day and

the end of the seventh day, and the abscissae formed by the 0°F. line and the 100°F. line. Then :

X planimeter units = 700°F. day units

A „ „ = $\frac{700A}{X}$ °F. day units

The mean temperature, T, is then $\frac{700A}{XT}$ °F.

If the area on which A is based is also 7 days, T becomes $\frac{100A}{X}$.

This method for determining the true weekly mean is by far the most satisfactory one. Although the theory may sound somewhat involved, the method may be used in practice by unskilled assistants after a little training. The mean weekly temperatures for a whole year were obtained by this method by a laboratory assistant in about five hours. With the charts used in these experiments, the zero line was not at 0°F., but at 20°F. For this reason, a constant represented by the area from 20-40°F. over seven days was added to each value of A, though this is not strictly necessary. The areas are obtained with surprising accuracy, and are consistently reproducible. A difference of 0.1% is exceptional between any two readings of area.

The method may be used for any type of recording instrument chart for any period of time. The only restriction imposed is that the scales must be linear; logarithmic, exponential or other scales are obviously unsuitable.

Mean temperatures for six weeks have been calculated, using the three methods mentioned. These are shown in

Fig 2. The differences are much more marked in the unmulched plots, where the daily variations are greater, than in the mulched plots. The shape of the curve remains similar in the unmulched plots when the tem-

MEAN WEEKLY SOIL TEMPERATURES CALCULATED BY THREE ALTERNATIVE METHODS

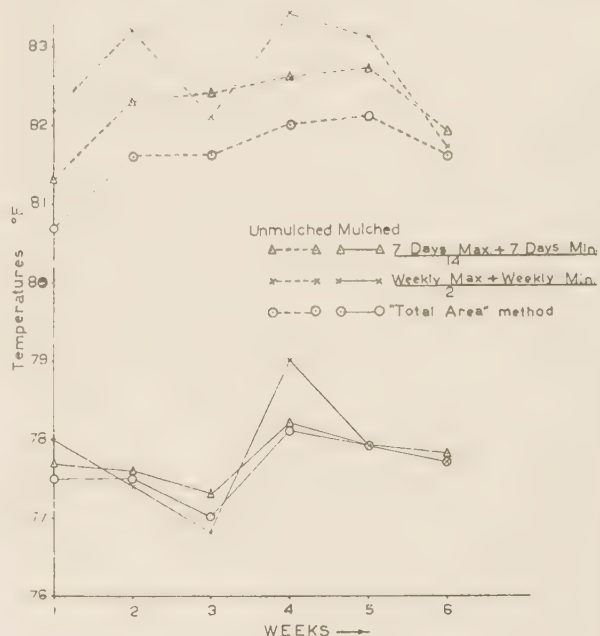


FIGURE 2

MEAN WEEKLY SOIL TEMPERATURES

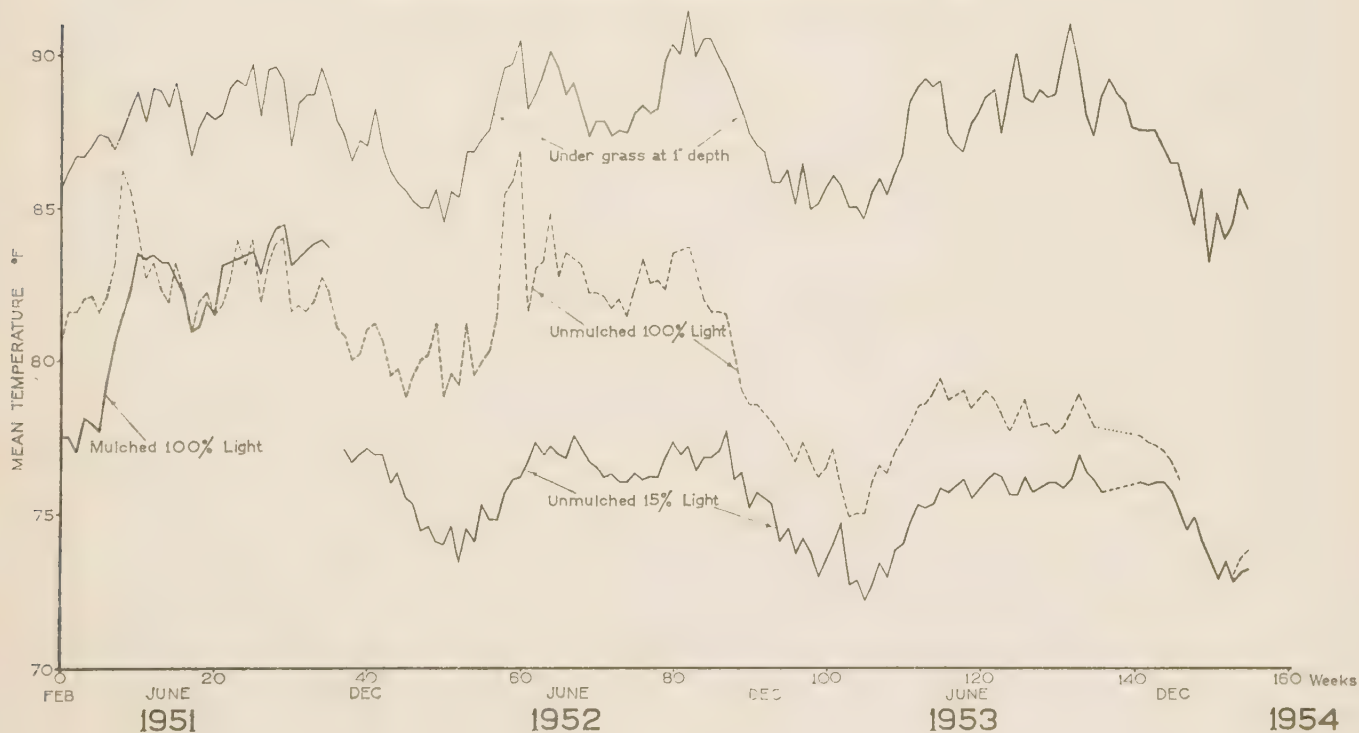


FIGURE 3

WEEKLY TEMPERATURE RANGES

Mulched 100% Light Unmulched 100% and 15% Light

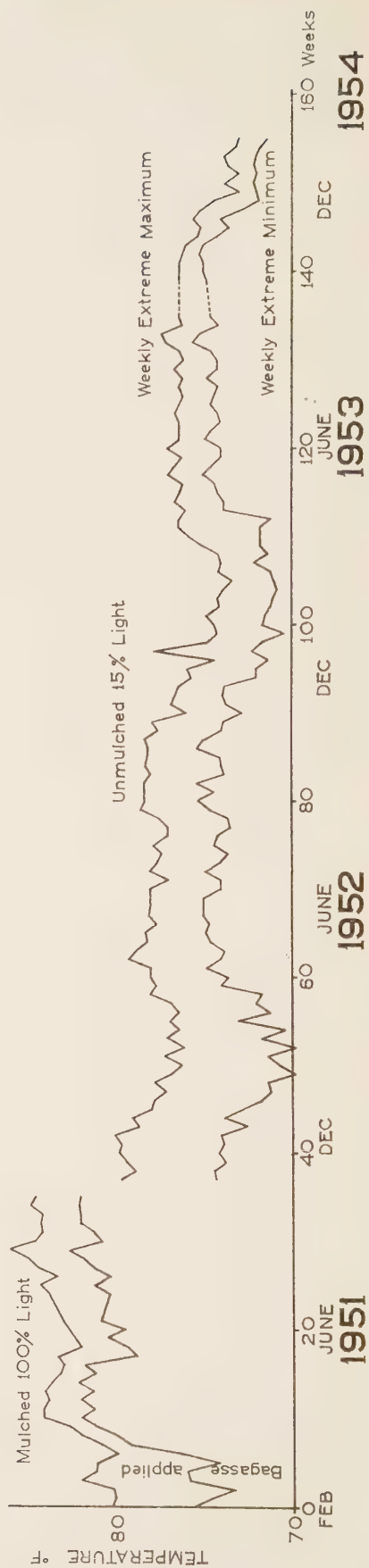
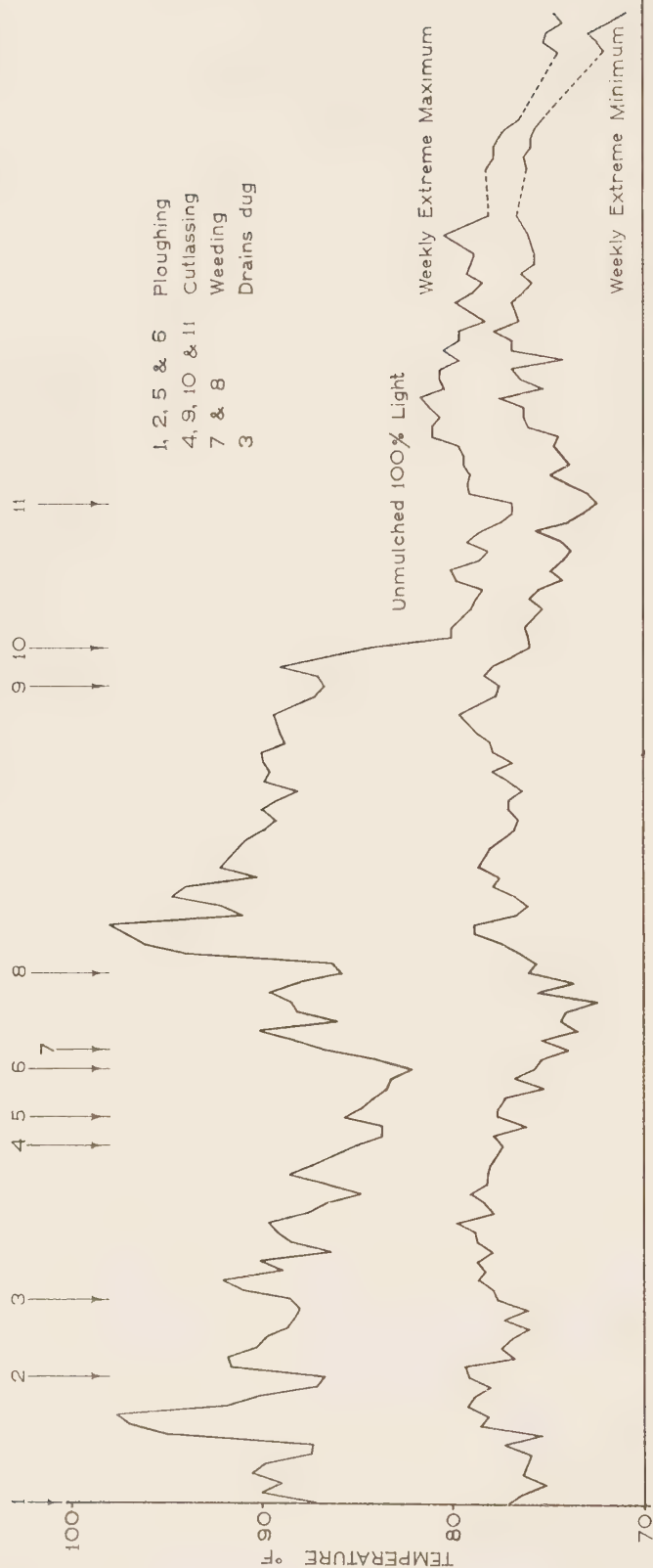


FIGURE 4

peratures are calculated by the "seven days maximum and minimum" method, and the "area" method, but the latter gives mean temperatures about 0.7°F. lower. The weekly "maximum and minimum" method gives variable results (sometimes the temperatures by this method as much as 1.6°F. too high). A great deal of accuracy is probably not lost in finding means when the temperature variations are smaller, as with the mulched plots, especially if the "seven days maximum and minimum" method is used. This method is, however, very much more laborious than the "area" method.

All the temperatures shown in Fig 3 have been calculated by the "area" method. The mean temperatures (also calculated by this method) for the mulched soil and the bare soil for the first 35 weeks recorded are 81.9°F. and 82.5°F. respectively. Mulching seems to have but little effect on mean soil temperature. There is a gradual decrease over the whole period of three years in all temperatures, which is undoubtedly due to increasing shade produced by the growing cacao trees.

The mean temperature under 15% light for the year 1952 was 76.1°F., while for the same period under 100% light, it was 5.6°F. higher. In 1952, the growing cacao had reduced the mean temperature in the 15% plot to

75.0°F., while the 100% became only 1.6°F. warmer than this. By the beginning of 1954, some three years after recordings were started, and three-and-a-half years after the trees were planted, the mean weekly temperatures had become almost the same under the two light intensities.

It is to be expected (1), (2) that the radiation per unit area on a horizontal surface received from the sun at Trinidad should show two weak maxima in about April and August, with a weak minimum in June and a strong minimum in December. This is reflected in the soil temperatures (at shallow depths) and may be observed in all three graphs presented in Fig. 3. It is most marked in the record from the 1 inch depth thermometer (shown for purposes of comparison) installed at the College Meteorological Station about one-quarter of a mile away from the Shade Experiment site. Rainfall tends to mask the effect to some extent, as does shade.

Fig. 4 shows the range of extreme maximum and minimum soil temperatures for the same three-year period. The gradual decrease in the range over the years is very noticeable. Again, it has taken about three years for the range from the 100% light plots to reach values similar to those of the 15% light plots. The range of values under mulch was very small and was about the same as that under

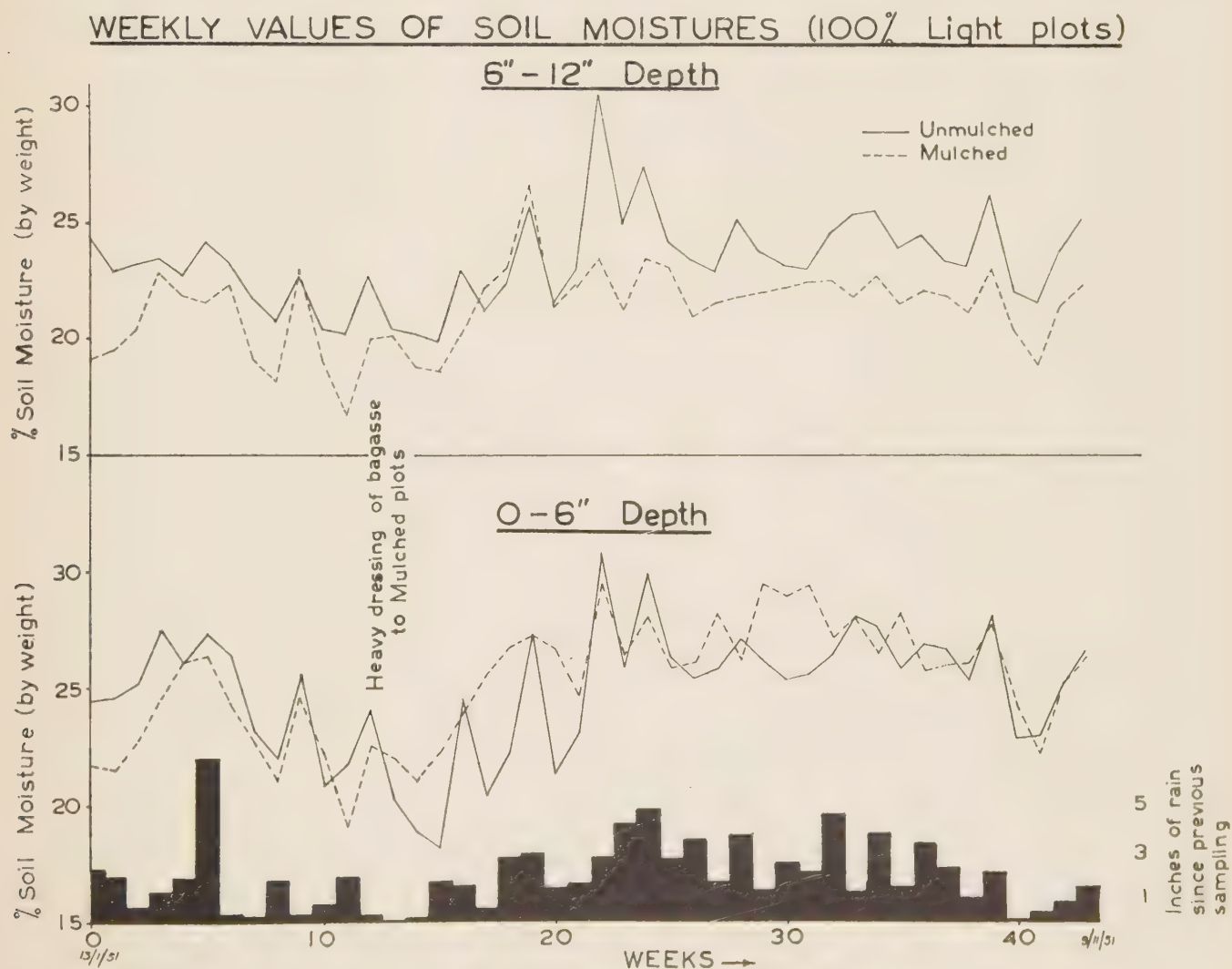


FIGURE 5

three-year-old trees, although the mean temperature was high.

The effect of various cultivations on the soil temperature may be seen in Fig. 4. Ploughing at dates (1), (2), (5) and (6) has tended to produce an increase in the maximum temperature ranging from about $1\frac{1}{2}^{\circ}\text{F.}$ to 6°F. Cutlassing of weeds at dates (4), (9), (10) and (11) has only exerted slight effect on the maximum temperature. None of the cultivations greatly affected the minimum temperature recorded. It is difficult to say whether the variations observed are really due to the soil treatment or whether they are due to climatic differences. It may be said, however, that whatever the effects on maximum temperatures, only increasing shade decreased the minima to any great extent.

Soil Moistures

Weekly records were kept for a period of about 10 months of the variation in the soil moisture under mulched and bare soils (100% light plots). Samples were taken in about 20 places, and were bulked together for moisture determinations. These records are shown in Fig. 5.

The differences between the treatments are not very marked. After applying the heavy dressing of bagasse (week 12), the moisture content of the top six inches of soil tended to be greater than that of the bare soil. This effect lasted for about 10 weeks. For the next month, the rainfall was heavy and there was little difference in soil moisture content. For three weeks the rainfall was somewhat smaller, and the mulched plots tended to retain more moisture than the unmulched. Thereafter, the two remained similar.

At the 6-12 inches depth, the mulch kept the soil moisture consistently lower throughout the whole period. In one instance (week 22) the difference between the two was 23% compared with 31%. The variation from week to week was smaller under the mulch. This may be seen from Table I, in which the mean moistures over the whole period are given, together with their standard errors.

TABLE I

Depth (ins.)	Mean moisture		Standard error	
	Mulch	No mulch	Mulch	No mulch
	Weight %			
0-6	25.3	24.9 ⁽¹⁾	0.39	0.42
6-12	21.4	23.4 ⁽²⁾	0.27	0.31

(¹) Difference not significant. (²) Difference significant.

Gravel Lenses

It was suspected that the area chosen for the experiment was not uniform. Paine (1940) some years ago investigated an area of the College Farm soil close to the shade experiment site. He found considerable variations in the amount of gravel visible on the surface and underneath, as well as variations in other soil features. Crop yields of Woolly Pyrol and Maize tended to be greater in areas where gravel was close to the surface.

It was felt that, because of the proximity of this known variable area, a survey of gravel depth should be made over the experimental site. The method chosen for this survey

was simple augering at intervals of 12 feet. The presence of gravel was indicated by the feel and sound of the auger. Thin layers of gravel, which the auger could penetrate with little difficulty, were ignored. It is true that gravel might have been recorded when the auger struck a large isolated stone. The chances of this happening were thought to be small. No indication could be obtained of the thickness of the gravel lenses by this technique. The best method of exploration would have been to dig pits, but for the detail required in this investigation it would have entailed the use of a prohibitively large number of excavations. In any case, pits were not desirable, since they would have interfered with the growth of the cacao.

Working on these lines, a map was constructed showing the variations in the depth of gravel below the surface. This is shown in Fig 6. Down to a depth of 2 feet, the depths are classed in intervals of 6 inches. From 2 feet to 4 feet, the depths are in intervals of 1 foot. Depths were not recorded below 4 feet.

It will be seen that Block I (unmulched) is fairly uniform with gravel mostly below 36 inches, if it is present at all. The small patch in the lower left-hand corner, in which gravel sometimes comes within 6 inches of the surface, occupies an area of less than 10% of the total area.

Block II, however, is heterogeneous. There are considerable areas in which the gravel is within 6 inches of the surface, and isolated patches with no gravel above 48 inches. The approximate areas involved are :—

Gravel depth (ins.)	% total area
0-6	31
6-12	33
12-18	17
18-24	2
24-36	3
36-48	8
48	6

By superimposing this map on a second one showing the positions of the experimental cacao trees, an estimate was made of the depth at which gravel occurred beneath each tree. Yield data were also obtained for the trees in grams of wet cocoa per tree. Rough observations had shown that areas in which gravel approached the surface tended to give higher yields and better-looking trees. These observations were, however, confined to Block II.

Using the figures for yield and depth, analyses of covariance were carried out to discover whether there were, in fact, significant correlations between them. An analysis was made over the whole of Block II without taking into account the fact that the effects of light, manures and clones might produce different regressions. The analysis showed that there was a significant 5% regression of yield on depth.

The next step was to determine whether there were significant differences between regression coefficients based on figures from the five light intensities taken separately. The differences were found to be non-significant.

Next, figures from the eight different manurial treatments were analysed separately. Again the differences were non-significant. Analyses were also made comparing regression coefficients of N *versus* no N treatments, P *versus* no P treatments and K treatments *versus* no K. In all cases the results were not significant.

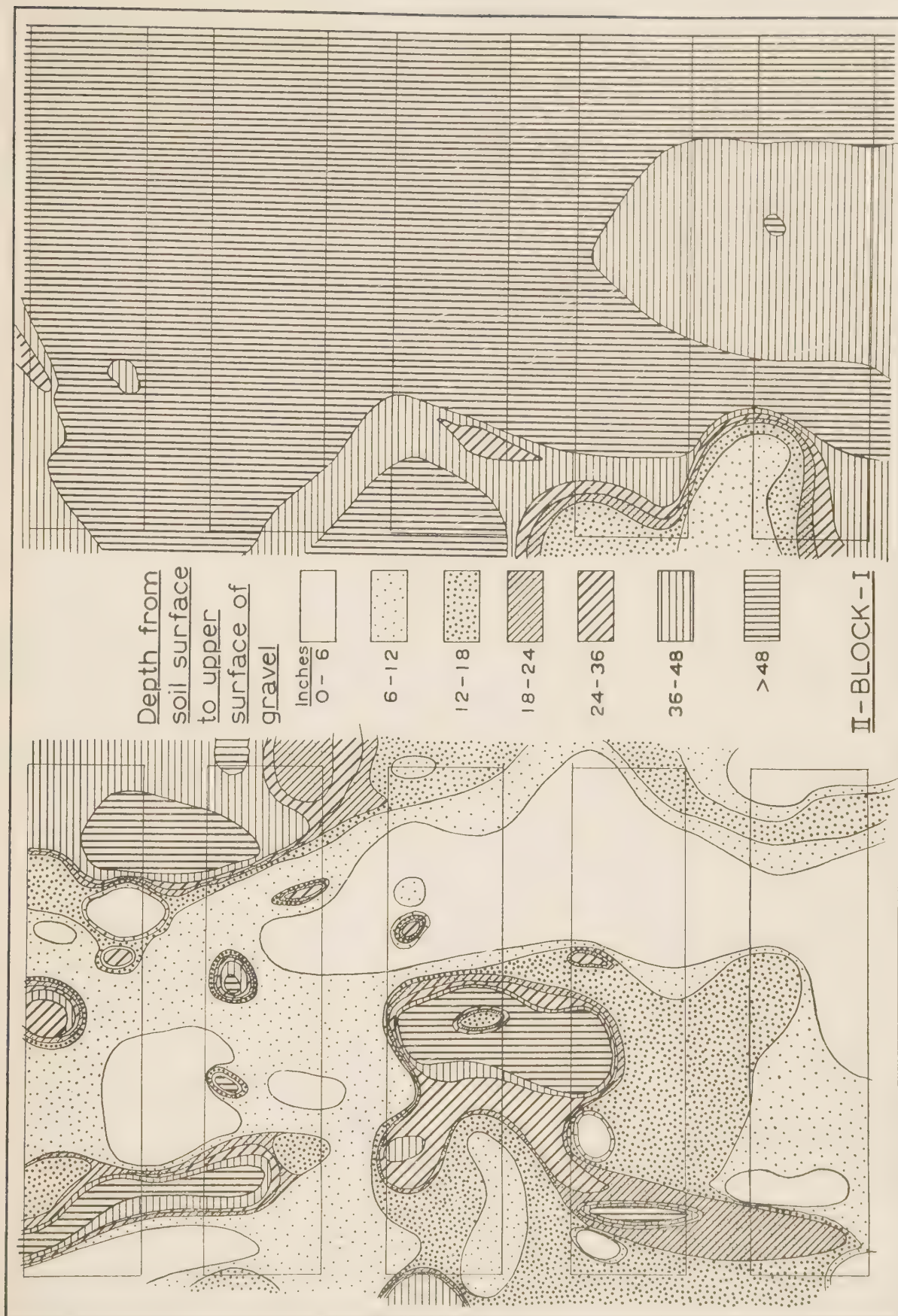


FIGURE 6

Data for three clones, ICS 1, 60 and 95, were then analysed separately. The results showed that the differences between the regression coefficients were highly significant. For ICS 95, the coefficient was $+0.32 \pm 1.7$ (non-significant); for ICS 60 it was -13.97 ± 6.9 (significant at the 5% level of probability), and for ICS 1 the regression coefficient was -36.49 ± 13.1 (significant at the 1% level). The number of degrees of freedom was in each case 34. The units are grams of wet cocoa per tree per inch depth below the surface.

Planters' experience has indicated that ICS 1 grows well only under good soil conditions, whereas ICS 95 and 60 tolerate poor soils more readily. It is, therefore, interesting to note that this analysis has shown the effect statistically. The presence of gravel layers close to the surface indicates that drainage is better at these places, and that penetration of the root tips is easier. Inspection of the roots of plants dug up in the early stages of the experiment do not seem to show any marked differences, but observations were not made with any great accuracy, since the gravel depth effects had not, at that time, been realised or investigated.

It will be interesting to carry out similar analyses in future years. If the trend still persists, the evidence that layers of gravel influence yields of cacao, particularly of ICS 1, will be greatly strengthened, and may help to explain differences between trees growing under apparently identical conditions.

Summary

(1) Records of soil temperatures and soil moisture contents have been taken in the Cacao Shade Experiment at the College Old Farm.

(2) Shade has exerted a considerable effect on soil temperature at a depth of 3 inches.

(3) The range of temperature was much greater under 100% light conditions than under 15% light.

(4) It takes about three-and-a-half years for the cacao to become sufficiently well developed under 100% light to reduce the temperatures to values similar to those under 15% light.

(5) Mulching tends to reduce soil temperature slightly and the range greatly.

(6) Soil moisture contents at the 0-6 inches depth are little affected by mulching, but tend to be lower under mulch at the 6-12 inches depth.

(7) A very significant correlation has been found between yields of cacao from ICS 1 clones and depth below the surface of gravel lenses which occur in Block II. There is a significant correlation for ICS 60 and no correlation at all for ICS 95.

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Nitrogen Partition in the Normal Cacao Leaf

by

R. G. Fennah

THE present investigation was made in order to provide a basis of reference with which nitrogen partition in leaves exposed to abnormal conditions might subsequently be compared, and is concerned with changes in the relative amounts of insoluble nitrogen, ammonia, amide and alpha-amino nitrogen during the life of leaves taken from trees grown under five different light intensities.

Material

Leaf samples were taken from clone ICS 60 in the Cacao Shade Experiment at the Imperial College of Tropical Agriculture (Farm Field, plots 4 and 5). The layout of this experiment has been described by Evans and Murray (1953: 67-76). Preliminary analyses of leaf material together with the earlier history of other crops in this area of the College Farm (Caribbean Commission, 1947) gave ground for belief that the status of nitrogen and potash in the untreated soil were markedly suboptimal. The rates of application of N and K in the experiment were not unduly heavy (Table I) and, accordingly, it was considered that trees in the NK plots, which had received the least nutrient amendments compatible with correction of known major deficiencies, were those nearest to "normal." The layout of the experiment was such that four trees were available for sampling at any one light intensity. Sampling began in March, 1952, when the plants were 19 months old, and continued until May, 1953.

TABLE I

Date of application	Rate of application of fertiliser in grams per plant	
	Sulphate of ammonia	Sulphate of potash
Jan. 11, 1952 ...	130	65
June 10, 1952 ...	130	65
Sept. 12-13, 1952 ...	227	114
Jan. 28, 1953 ...	227	114
May 18, 1953 ...	227	114

Methods

(a) Sampling.

The earliest samples taken comprised leaves of three age-groups, (1) young, (2) mature, and (3) senile. These were defined as (1) half or three-quarters of full size with immature coloration; (2) full size, dark green, situated near the apex of the branch or close behind the apical

flush; (3) golden yellow, but requiring a distinct pull for removal. Repeated analyses showed consistent differences between leaves of different age-groups at any one light intensity, but except in very old leaves, fluctuation in values—often with reversal—between leaves of similar age-groups (as defined) at different light intensities. An attempt was made to reduce this variation by selecting leaf samples on narrower limits for age by the following grouping: (1) very young, one-third of full size; (2) three-quarters of full size with juvenile coloration; (3) mature, fully green; (4) senescent, green mottled freely with yellow; and (5) senile, golden yellow. With these samples there was again apparent consistency in the "senescent" and "senile" classes between different light intensities, but results otherwise still showed inconsistent variation in this comparison. This procedure was discontinued in favour of a method (Fennah, 1953) in which the samples to be compared each comprise a "foliar series" as it occurs along a branch. In one form of the method branches were selected at the onset of a flush of growth and the leaves were numbered, the most distal leaf being marked and leaf scars being numbered if the sequence of leaves along the branch was interrupted. Half of each leaf was removed by cutting near and parallel to the midrib, and was analysed separately. After an appropriate interval (of about two months) the remaining halves were collected and similarly analysed.

Where the amount of material in each leaf was inconveniently small (as was liable to occur with very young leaves) leaves of equal position number from several flushing shoots on the same tree were bulked together. For comparison with the results obtained by the foregoing, analyses were made of serially numbered individual leaves taken from one side of a branch, then, after an appropriate interval, from the other. In addition, buds in the initial stages of opening were tagged at a recorded date, and after an interval sufficiently long to permit extension and development of the slowest shoots the new growth was collected, the leaves numbered in sequence, and analysed. For observations on leaf longevity such tagged shoots were left to develop: advantage was also taken of a general natural "tagging" of the flush of early March, 1952, by the feeding punctures inflicted by an unprecedentedly large population of *Leucothrips*, which resulted in the development of light but highly characteristic scarification which persisted on the leaf throughout its life.

In planning the sampling for comparison of the effect of different light intensities it was recognised that increase in age of the leaf was in general accompanied by a decrease in the amount of incident light, as the oldest leaves were

nearer to the centre of the tree. This was reduced as far as possible by restricting the branches available for selection to those which were exposed, at least in their distal portions, directly to the light source. This ensured that young and at least the earlier mature leaves were representative of their appropriate "light" values, but did not dispose of the difficulty with regard to older leaves (with the exception of some of those in 100% light which were exposed to full light as, being short-lived, they were not far down the stem). Accordingly, in order to provide values for comparison with those of the routine samples old leaves were specifically sought (on the selected trees) which through accident of position had remained as free as possible from mutual shading: such leaves were classified by their relative position in the series on the branch and by their degree of discoloration.

As stated above, several applications of fertiliser were made during the course of the investigation. No provision existed for protecting the soil surface, and, as noted by Evans (1953 : 49) rapid uptake of fertiliser may occur after a light shower of rain in dry weather. It was outside the scope of the present investigation to follow nitrogen partition in the leaf under conditions other than normal, and, accordingly, the times of routine sampling were spaced so as to leave a substantial interval after the application of fertiliser.

In the material analysed the relation of values to time proved to be satisfactorily constant, but it was found that there could be substantial variation, at a single light intensity, in the time taken for a bud to extend into a shoot and for the leaves of that shoot to harden. It is not known whether this is due to seasonal change or to nutritional levels, but it was clear that it did not vitiate in any appreciable particular comparison of values for similar leaves and branches at different light intensities taken at any one collection.

(b) Analytical.

All leaf samples were collected between 8.00 a.m. and 9.00 a.m., and each leaf, as removed, was placed in an appropriately numbered envelope. The leaves were immediately taken to the laboratory, and if necessary the leaf-surface was dried by lightly wiping with a cloth. The petiole and midrib were rapidly excised and the lamina weighed. A sample of this tissue (usually 10 gm) was weighed, transferred to the drying oven and dried to constant weight at about 49°C. Hence the dry weight of the lamina was calculated. Glutamine N, total amide N, ammonia N and insoluble N were determined by the methods of Vickery, Pucher and Leavenworth (1935). Alpha-amino N was measured by a method derived from that of Pope and Stevens (1939) and Haddock and Evers (1932). The ammonia distillations were carried out under uniform conditions with two sets of three stills, each set being maintained in a common water bath, of which the temperature was held between 40° and 38° for the ammonia N, glutamine N and total amide N determinations and between 70° and 60° for the remainder. The distillate was collected in 5 ml. of 2% boric acid with 0.1 ml. of an indicator comprising a 5 : 1 mixture of 0.1% bromocresol green and 0.1% methyl red in 95% ethyl alcohol. N/200 HCl was used for the titration.

Total nitrogen. Fresh leaf tissue (2 or 3 gm.) was digested with sulphuric acid in the presence of hydrogen peroxide as a catalyst. (Miller and Miller, 1948.)

Insoluble nitrogen. Fresh leaf tissue (1.0 or 1.5 gm.) was macerated with 70% ethyl alcohol in a blender and allowed to stand for 8 hours at room temperature. The alcohol was removed and the residues extracted with boiling water for 30 minutes, after which the water was removed and the residues digested with sulphuric acid with hydrogen peroxide as catalyst. The insoluble N includes protein and theobromine N. On account of the slight solubility of the latter in hot water it is possible that the values obtained are slightly below the true sum of these constituents.

Soluble nitrogen. Fresh leaf tissue (10 gm.) was rapidly chopped into slices with a razor blade and macerated in a blender with water (100 ml.) for four or five minutes, the longer period for tougher and older leaves. The blend was sampled as soon as complete by withdrawing an aliquot up a glass tube of 5 mm. bore marked to contain 10 ml., and the sample was rapidly inspected for even consistency. The aqueous blends of old leaves require rather vigorous agitation just as the aliquot is withdrawn in order to ensure even dispersion of the fragments.

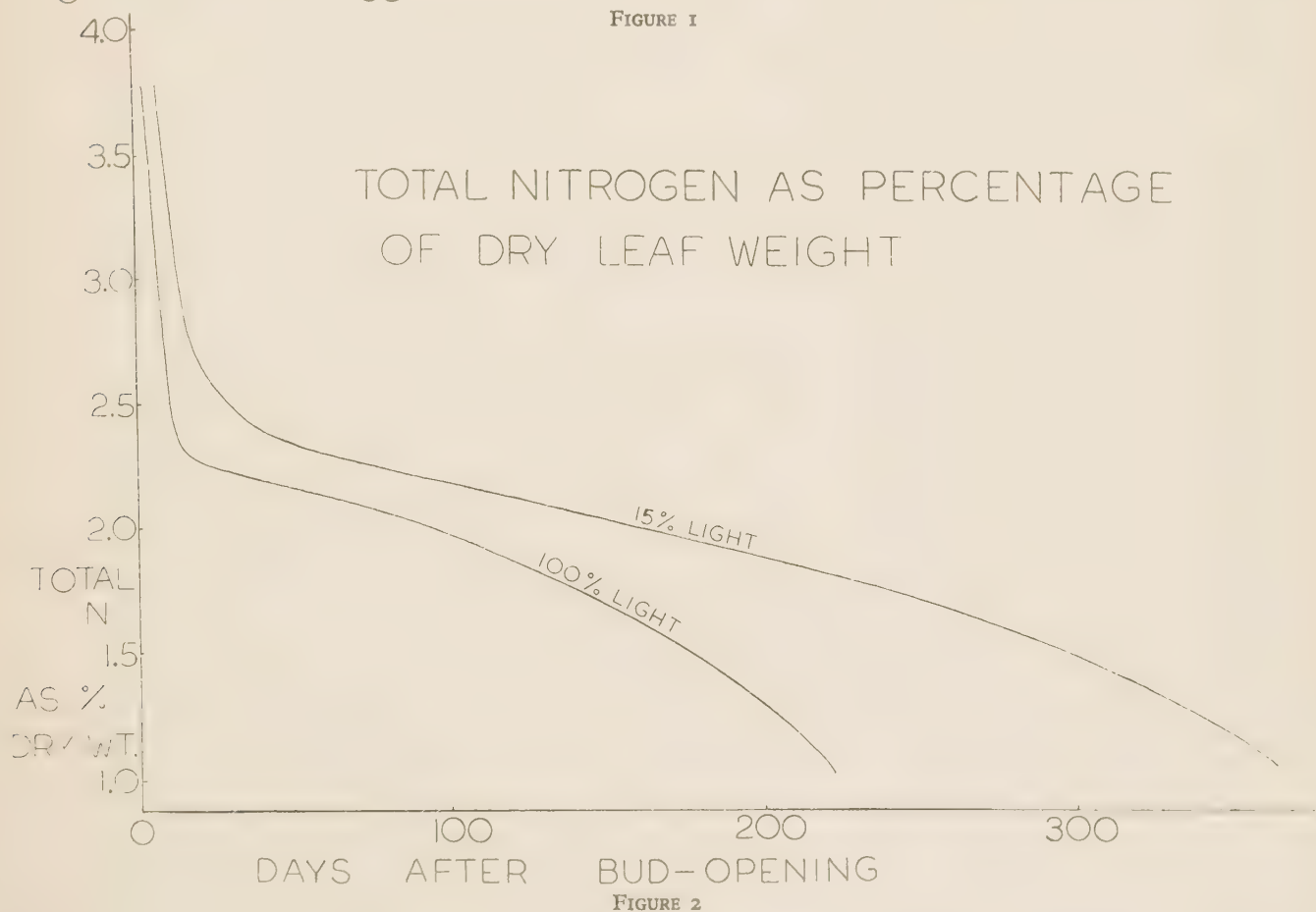
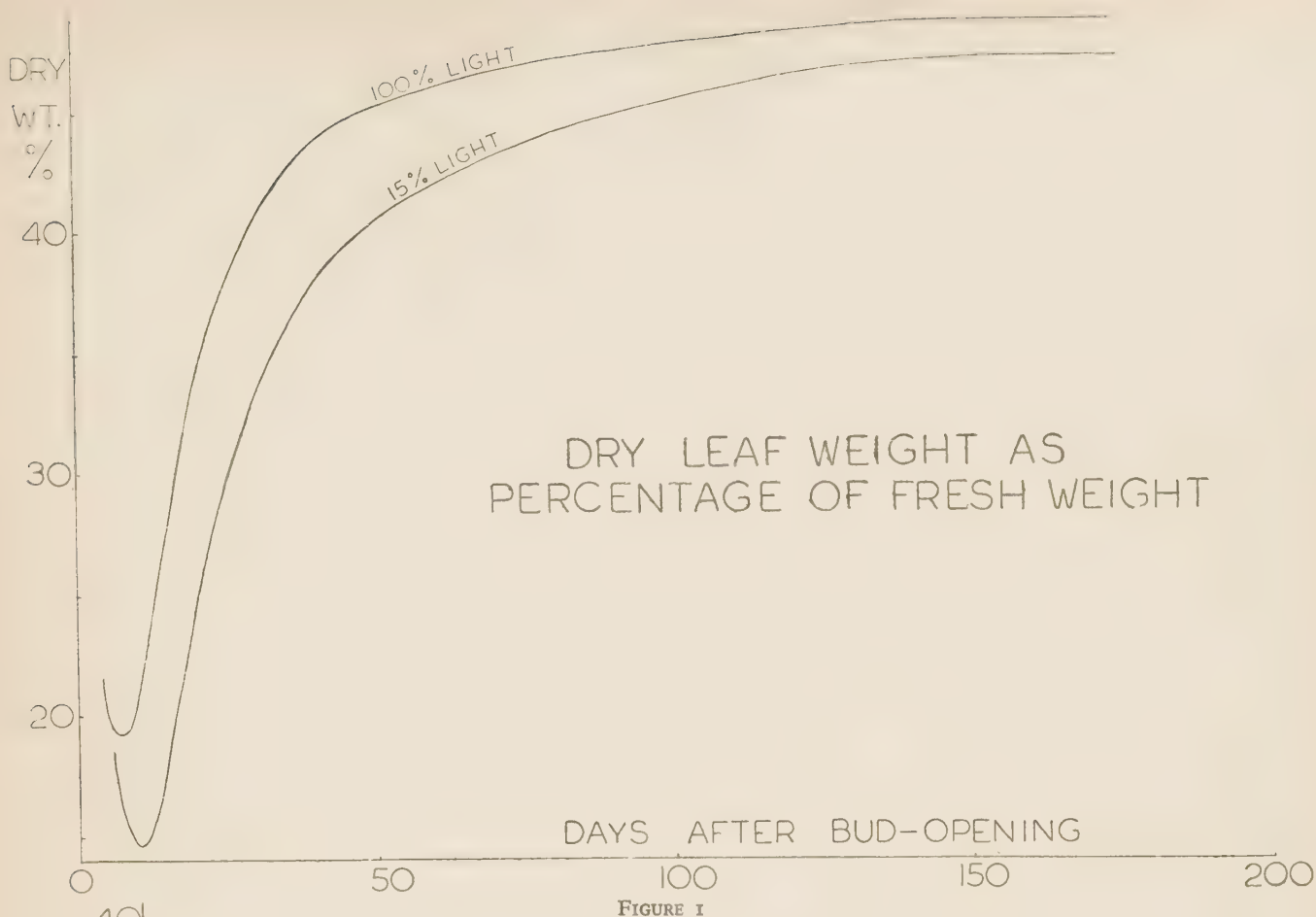
Ammonia N. To a 20 ml. aliquot, phosphate borate buffer, pH 6.5 (10 ml.) and 5% borax in N/2 NaOH (5 ml.) were added immediately before distillation (at 40°C.).

Glutamine N. To a 10 ml. aliquot, phosphate borate buffer (10 ml.) of about pH 6.8 (to give a final value of pH 6.5) was added, and the mixture was heated for two hours at 100°C. After cooling the mixture was transferred to the ammonia still and 5% borax in N/2 NaOH (5 ml.) was added immediately before distillation (at 40°C.). Results were corrected for free ammonia.

Total amide N. A 10 ml. aliquot was mixed with 6N H₂SO₄ (2 ml.) in a tube fitted with an air condenser and was heated for three hours at 100°C. The contents of the tube, after cooling, were transferred to the ammonia still, 1N NaOH (about 15 ml.) was added to neutralise the mixture to thymolphthalein, and 5% borax in N/2 NaOH (10 ml.) was added just before distillation (at 40°C.). Results were corrected for free ammonia.

α-Amino N. A 10 ml. aliquot was adjusted to pH 9.7 with 1N NaOH, mixed with copper phosphate suspension (30 ml.), made up to 50 ml. with water and filtered. A 2 ml. aliquot was transferred to a separating funnel, 40% tartaric acid (1 ml.), concentrated ammonia (1 ml.) and 0.1% Na diethyl dithiocarbamate (2 ml.) added. The Cu complex was extracted into four 2.5 ml. portions of CCl₄ and determined spectrophotometrically.

Nitrate N. This was not followed. Rapid tests of mature leaf tissue were made at intervals by the phenol disulphonic acid-ammonia method. The nitrate level, as so estimated, was usually negligibly low, but samples taken in the middle of the dry season of 1953 contained nitrate N in excess of the values for ammonia in mature tissue. As far as the present series of samples is concerned there is reason to regard the presence of nitrate in the leaves as no more than a reflection of its current availability in the soil.



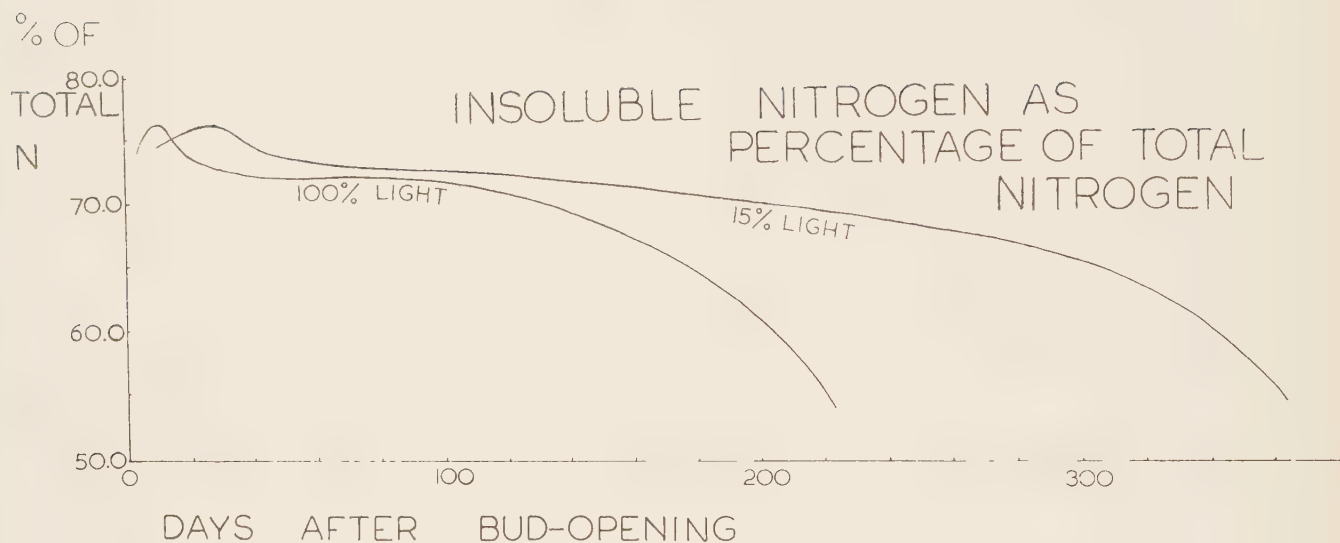


FIGURE 3

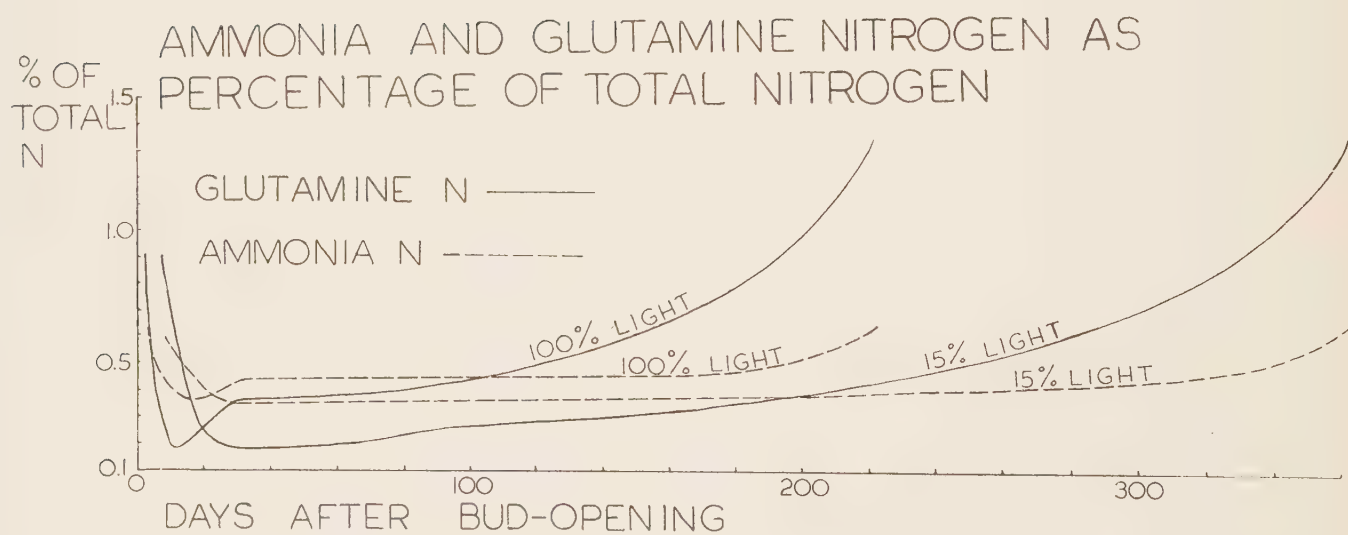


FIGURE 4

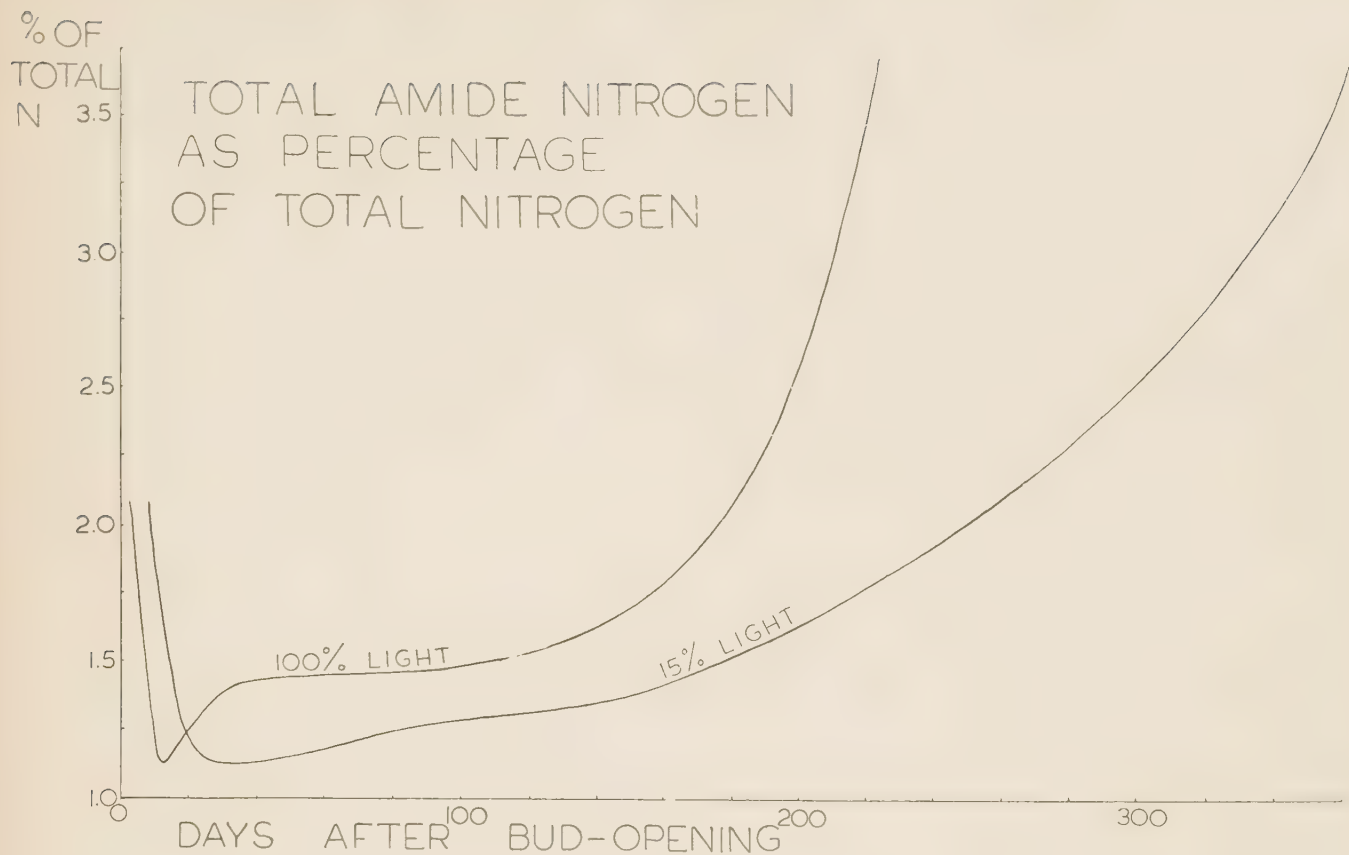


FIGURE 5

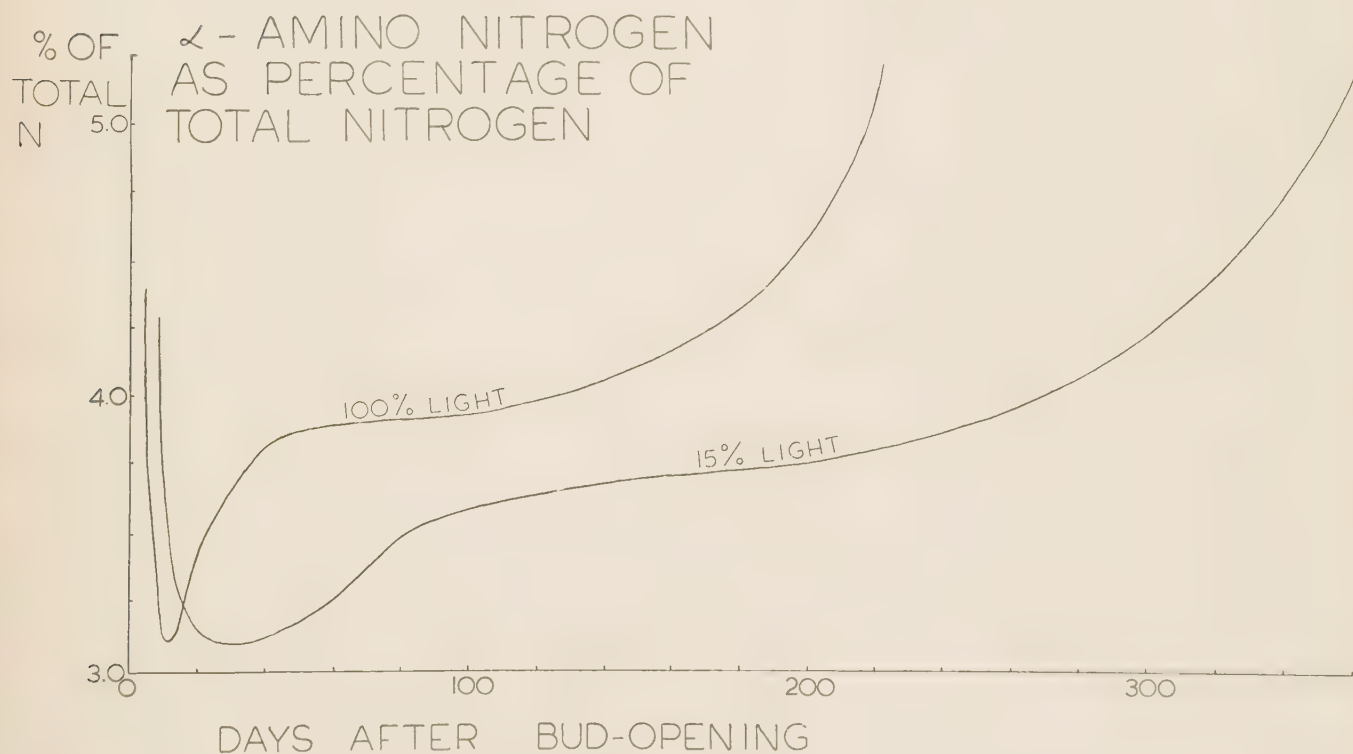


FIGURE 6

Results

The relationship between dry leaf weight, total nitrogen, insoluble nitrogen, ammonia, glutamine, total amide and α -amino N, at different light intensities in leaf tissue throughout its functional life is shown graphically in Figs. 1-6 and in tabular form in the Appendix.

Discussion

Dry Weight.

The time relationship of the ascending part of the curve is an average of the values obtained. It is possible under certain conditions for a flush to extend and harden in about 10% less time than the shortest shown or to be retarded by some 20% of the longest. The values at which the curves terminate represent an average of the highest-reading samples: it is not infrequent for leaf-shed to occur when the moisture content is not less than 56% of the fresh leaf weight.

Total Nitrogen.

Average values for the samples are given. The range of absolute values traversed by the subhorizontal part of the curve applies, of course, only to the present samples, but the form of the curve is of general significance. In an exploratory analysis of a few samples from the same clone from 100% and 25% light blocks in a treatment not including nitrogenous fertiliser the curve was similar and the subhorizontal portion ranged through values some 0.3% lower.

Insoluble Nitrogen.

The separation of insoluble nitrogen into protein and theobromine nitrogen was not attempted. In the bean theobromine nitrogen forms rather more than a fifth of the insoluble nitrogen (Hardy and Rodrigues, 1953). Birch (1941: 24) in following changes in nitrogenous composition of forastero cacao during fermentation stated that changes in theobromine nitrogen proved to be small in comparison with the relatively large changes in total and protein nitrogen. Vickery, Pucher, Wakeman and Leavenworth (1937: 812) when discussing the changes in nicotine nitrogen in tobacco leaves concluded that "nicotine cannot be regarded as an active metabolite." If this is true of theobromine in cacao leaves, or if the amount of theobromine nitrogen in the leaves is not greater than that quoted above for the bean, the changes shown by insoluble nitrogen will portray sufficiently well those which occur in protein nitrogen.

Ammonia, amide and α -amino nitrogen.

The values determined for these forms of nitrogen make up about a sixth of the total soluble nitrogen. Collectively and separately their abundance is inversely related to that of insoluble nitrogen.

The curves show a slow and uniform rise in soluble nitrogen after the peak of protein synthesis has been passed. The partition of nitrogen in the closing stages of the life of the normal leaf was cursorily examined in four analyses which gave the average values shown below (Table II). The leaf samples were chosen subjectively from the 100% and 25% light plots in so far as they fitted into the following classes, listed in order of increasing physiological age: (1) green (usually bright green) heavily mottled and marbled with yellow areas; (2) uniformly golden yellow, firmly attached; (3) golden yellow, sometimes blotched

with chocolate brown intervenally, dropping at a touch; (4) rich chocolate brown, sometimes with slight traces of yellow, still turgid, dropping at a touch. The criterion of firmness of attachment is not as perfectly concordant with colour change as the above grouping might suggest.

TABLE II

Leaf class	Nitrogen expressed as percentage of total nitrogen				
	Ammonia	Glutamine	Total Amide	α -Amino	Insoluble
(1)	0.51	0.9	2.0	3.8	63.0
(2)	0.53	1.2	2.2	4.8	61.1
(3)	0.56	1.4	2.8	5.5	60.0
(4)	0.64	1.8	3.6	6.5	58.1

The hydrolysis of protein is accelerated at the final stage when the leaf is ready to fall, but there is still no sign of breakdown in the mechanism of amide synthesis at this stage.

Nitrogen partition in relation to light.

If the maximum protein synthesis is taken as indicating the highest degree of ascendancy of anabolic over catabolic activity, it is evident from the curves that there is no appreciable difference between the trees grown at different light intensities if comparison is made on the basis of equal physiological age. If comparison is made on the basis of equal temporal age then there is a difference in favour of the higher light intensities during the flush, a period of sixteen to twenty days, but thereafter the difference changes in favour of the more shaded trees. The comparison of total nitrogen as percentage dry weight on a basis of equal temporal age shows throughout a difference in favour of the more shaded trees.

Summary

(1) The changes in proportion of dry leaf weight to fresh leaf weight, total nitrogen to dry leaf weight, and insoluble nitrogen, ammonia, glutamine, total amide and α -amino nitrogen to total nitrogen have been followed throughout the functional life of normal cacao leaves grown at different light intensities.

(2) Other treatments being equal, nitrogen partition in the leaf is not significantly different between leaves of equal physiological age when they are grown at different light intensities.

(3) In leaves of equal temporal age total nitrogen, in relation to dry weight, is higher in shaded trees. For approximately the first sixteen to twenty days after bud opening insoluble nitrogen forms a relatively larger part of the total nitrogen of unshaded leaves than of shaded; thereafter the difference changes in favour of the shaded trees. This relationship is reversed with reference to the relative amounts of the soluble nitrogen fractions with the exception of nitrate nitrogen.

Acknowledgments

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APPENDIX

Crude dry leaf weight as percentage of fresh weight

Days after bud-opening	Light intensity				
	100%	75%	50%	25%	15%
9	19.85	18.46	16.93	15.40	14.82
11	21.56	19.52	17.58	15.54	14.73
13	25.02	22.21	19.46	16.74	15.62
15	27.56	24.74	22.08	19.32	17.70
20	34.23	31.33	28.66	26.05	24.37
25	37.78	35.48	33.12	30.84	29.56
30	40.65	38.57	36.47	34.31	33.23
60	46.13	45.05	43.94	42.85	42.12
80	47.27	46.44	45.65	44.82	44.24
100	47.94	47.23	46.56	45.90	45.50

Total nitrogen as percentage of dry weight

Days after bud-opening	Light intensity				
	100%	75%	50%	25%	15%
9	2.75	2.99	2.23	3.47	3.62
11	2.45	2.70	2.96	3.21	3.37
13	2.37	2.58	2.78	2.98	3.11
15	2.32	2.48	2.64	2.80	2.90
20	2.27	2.39	2.51	2.63	2.70
25	2.24	2.31	2.41	2.52	2.57
30	2.22	2.30	2.37	2.45	2.50
60	2.12	2.17	2.22	2.26	2.29
80	2.05	2.10	2.15	2.20	2.23
100	1.96	2.02	2.09	2.15	2.18
150	1.67	1.78	1.90	1.98	2.01
200	1.28	1.48	1.67	1.80	1.85
250	—	1.11	1.37	1.57	1.68
300	—	—	1.02	1.27	1.45

Insoluble nitrogen as percentage total nitrogen

Days after bud-opening	Light intensity				
	100%	75%	50%	25%	15%
9	76.00	75.54	75.06	74.58	74.30
11	76.10	75.62	75.15	74.68	74.40
13	75.70	75.39	75.08	74.78	74.60
15	75.21	75.11	75.00	74.87	74.79
20	74.00	74.33	74.67	75.00	75.20
25	73.20	73.95	74.70	75.45	75.90
30	72.79	73.69	74.58	75.47	76.01
60	71.91	72.23	72.57	72.90	73.09
80	71.80	72.02	72.74	72.47	72.58
100	71.47	71.75	72.00	72.25	72.39
150	69.01	69.47	69.94	70.42	70.69
200	61.00	63.71	65.59	67.30	68.47
250	—	55.73	61.20	64.10	65.70
300	—	—	—	59.80	62.30

Ammonia nitrogen as percentage total nitrogen

Days after bud-opening	Light intensity				
	100%	75%	50%	25%	15%
9	0.43	0.48	0.53	0.57	0.60
11	0.39	0.43	0.48	0.52	0.55
13	0.37	0.41	0.46	0.50	0.52
15	0.36	0.39	0.43	0.46	0.48
20	0.38	0.39	0.41	0.43	0.44
25	0.40	0.40	0.39	0.39	0.39
30	0.43	0.41	0.39	0.37	0.36
60	0.44	0.42	0.39	0.37	0.36
80	0.45	0.43	0.41	0.38	0.37
100	0.45	0.43	0.41	0.38	0.37
150	0.46	0.44	0.42	0.40	0.37
200	0.52	0.48	0.45	0.41	0.38
250	—	0.62	0.55	0.47	0.40
300	—	—	—	0.56	0.43

Glutamine nitrogen as percentage total nitrogen

Days after bud- opening	Light intensity				
	100%	75%	50%	25%	15%
9	0.23	0.38	0.53	0.68	0.78
11	0.18	0.32	0.45	0.59	0.67
13	0.19	0.29	0.39	0.49	0.55
15	0.20	0.28	0.36	0.44	0.49
20	0.25	0.27	0.30	0.32	0.34
25	0.32	0.29	0.26	0.24	0.22
30	0.35	0.31	0.27	0.22	0.18
60	0.38	0.33	0.28	0.23	0.20
80	0.40	0.35	0.31	0.26	0.23
100	0.45	0.40	0.35	0.31	0.28
150	0.60	0.53	0.46	0.39	0.35
200	0.98	0.76	0.62	0.47	0.40
250	—	1.19	0.88	0.65	0.53
300	—	—	—	0.92	0.71

Alpha-amino nitrogen as percentage of total nitrogen

Days after bud- opening	Light intensity				
	100%	75%	50%	25%	15%
9	3.30	4.13	4.97	5.80	6.30
11	3.10	3.26	3.42	3.58	3.67
13	3.11	3.18	3.25	3.32	3.36
15	3.15	3.18	3.22	3.25	3.28
20	3.40	3.33	3.26	3.19	3.15
25	3.55	3.43	3.31	3.19	3.12
30	3.65	3.50	3.35	3.20	3.10
60	3.90	3.72	3.54	3.36	3.25
80	3.92	3.80	3.68	3.56	3.49
100	3.94	3.84	3.74	3.64	3.58
150	4.11	4.00	3.89	3.78	3.71
200	4.58	4.35	4.12	3.89	3.75
250	—	5.00	4.50	4.13	3.76
300	—	—	—	4.62	4.23

Total amide nitrogen as percentage of total nitrogen

Days after bud- opening	Light intensity				
	100%	75%	50%	25%	15%
9	1.35	1.56	1.77	1.97	2.10
11	1.12	1.31	1.50	1.69	1.80
13	1.13	1.27	1.42	1.56	1.65
15	1.15	1.25	1.34	1.44	1.50
20	1.25	1.25	1.24	1.24	1.23
25	1.31	1.27	1.22	1.18	1.15
30	1.35	1.29	1.22	1.16	1.12
60	1.45	1.37	1.30	1.22	1.18
80	1.46	1.40	1.34	1.28	1.25
100	1.48	1.43	1.37	1.32	1.29
150	1.69	1.60	1.52	1.43	1.38
200	2.59	2.32	2.06	1.80	1.65
250	—	—	2.75	2.30	2.03
300	—	—	—	3.00	2.55

A New Technique in the Vegetative Propagation of Cacao

by

D. B. Murray

ALTHOUGH the main factors associated with the successful rooting of cacao cuttings have been established by Evans (1953), one important feature still demands attention, the high cost of production of the plants. At present two main techniques are available: either closed bin propagators with a balanced number of hardening bins, or open spray beds with rooting occurring under a continuous mist spray. The first method is the more efficient for rooting but is very expensive both in capital outlay and running costs. The open spray method, though slightly less efficient, is cheaper in operation but requires large quantities of water at a fairly high pressure. A new technique has now been developed which aims at reducing both the capital outlay and the running costs of producing rooted cacao cuttings in fairly large numbers.

Evans (1953) has described a method of hardening rooted cuttings using a specially developed glasshouse with a centrifugal humidifier. This is essentially a device for producing a saturated atmosphere without appreciable droplet formation such as occurs with even low-delivery spray-nozzles. The humidifying chamber is fitted with four shelves and after putting the rooted cuttings in baskets these are arranged on the shelves (Fig. 1). The humidifier is operated continuously during the day for four to five days and then intermittently for three to four days after which the hardened plants are removed.

It was first shown that rooting also could be effected in this chamber. Twenty-four baskets each were filled with composted sawdust and potting soil. Cuttings were prepared in the usual way and, after the hormone dip, were inserted in the baskets. These were watered lightly and then placed in the humidifying chamber. The humidifier was run continuously during the day from 7 a.m. to 6 p.m. for twenty-four days when the cuttings were examined by removal from the baskets. It was found that 21 out of the 24 cuttings in the sawdust had produced roots, whereas in the potting soil only 4 had rooted. 16 of those in the soil had rotted at the base, a result of poor aeration.

There was, however, no great advantage in producing rooted cuttings in sawdust, for subsequent growth in such an infertile medium would be unsatisfactory and the alternative of repotting in soil would give no advantage over the traditional methods. It was, therefore, necessary to devise a method whereby rooting could be achieved in a rooting medium with subsequent growth of the roots into soil. By preparing a basket with a central core of the rooting medium surrounded by potting soil it was hoped to achieve this. If the moisture and air relations at the base of the cutting in the central core were satisfactory, rooting would occur and the roots would quickly grow

into the surrounding potting soil. An established plant would thereby be achieved in one operation.



FIGURE 1

Humidifying chamber showing baskets arranged in five tiers and centrifugal humidifier (top right).

A wooden cylinder of about 2 inches diameter was placed centrally in a basket around which was packed potting soil. The wooden cylinder was then removed and the space filled with a core of composted sawdust. Cuttings prepared in the usual manner were inserted in the baskets with the base of the cutting in the sawdust core (Fig. 2).

After twenty-eight days in the humidifier, roots began to emerge from the sides of some of the baskets. Examination of a number of the plants by removal from the baskets showed the percentage and intensity of rooting to be as good as the best results from orthodox closed bins. Moreover, the potting soil was found to be in good physical condition having maintained its crumb structure and showing little sign of water-logging. A thermohygrograph in the chamber gave an unbroken record of 100% humidity and a temperature range of 74-88°F. Water consumption of the humidifier was some 6-8 gals./hour.

The next point to be investigated was the stage of removal from the humidifying chamber to the open greenhouse floor. For this purpose a sample of plants, some with roots through the basket, some without, was removed from the chamber to the greenhouse after thirty-two days and left for a week.



FIGURE 2

Arrangement of basket showing cutting inserted in central core of rooting medium surrounded by potting soil.

The plants that died during this time were found to have failed to root, but it appeared that once rooting was satisfactory the plants could be transferred from the 100% humidity of the chamber to normal atmospheric humidity without fear of loss. This was not unexpected for the so-called hardening is not an acclimatisation process but a phase of development of roots to the stage where their water-absorbing capacity is capable of supporting the plant at atmospheric humidity. The time at which the plants can be removed from the humidifying chamber can, therefore, be judged by the emergence of the roots through the weave of the basket.

Since the use of the rooting medium as a core inside the potting soil appeared practicable, the next trial compared different sizes of core and different rooting media. Truncated cones were tried 9 inches long with bottom diameters of 1½ and 2½ inches and top diameters of 2½ and

3 inches respectively. Rooting media were Toco sand, composted sawdust and composted sawdust over Toco sand. The first roots emerged in twenty-three days through the mesh of two baskets with a sand core, remarkably rapid establishment. The results indicated that there was little to choose between the three types of media, but that the larger core was more satisfactory, particularly with sawdust. Unless sand had proved markedly superior, sawdust is to be preferred since it is easier to obtain and much lighter to transport. Other media tried in the core were vermiculite and coconut-fibre residue. Vermiculite proved just as good as sawdust and has many advantages in propagation, being light, durable and sterile. The major objection to its use is expense. The conclusion is that composted sawdust, usually an easily obtainable cheap material, is as good as any other medium tried.

The next factor investigated was the light intensity in the chamber. For hardening it had been found that the plants at ground level, with four tiers of plants above, received enough light for establishment through the sides of the chamber. It was necessary to see whether this would also be the case for the complete process. Five clones were used and each clone was represented at each level. There was some indication that results were slightly worse for the bottom two tiers, but there appears to be sufficient light for all five. The difficult rooting ICS 1 gave satisfactory rooting only on the top tier. As in closed bins, certain clones are always quicker and better rooting than others. The light intensity through the roof as measured by a light meter was between 20% and 25% of full light and this was reduced 5% to 10% by the mist from the humidifier.

A trial of single leaf cuttings gave some 68% established plants at six weeks. These were held upright in the basket with a sliver of wood. Rooting of single leaf cuttings is rather slower than ordinary stem cuttings.

Where orthodox closed bins already exist it is possible to use these in combination with the humidifier. Cuttings were set in closed bins and examined at eighteen days. Those showing signs of basal swelling were transferred to cored baskets in the humidifier where they gave 100% rooting in a further fortnight. This results in a considerable saving in the time and labour normally needed for examination and removal of rooted cuttings and their careful transfer to baskets for hardening. Also the bins can be emptied and new cuttings set more frequently thereby increasing potential production of plants.

Discussion

It has been demonstrated that a technique for producing rooted plants in one operation is practicable. What are its disadvantages and advantages and is it economic? One disadvantage is that a supply of electricity is necessary, though it is possible to drive the humidifier directly from a petrol engine. Power failure might be serious but if this was only likely to occur over a short period, an auxiliary system of spray-nozzles could be installed. On the other hand the capital cost of building the equivalent capacity of closed bins and hardeners is far higher than the cost of the humidifier and glasshouse. They occupy more than five times the area with the consequent increase in area of concrete floor and of artificial shade. Their labour requirement for normal running is high. This includes the watering of the bins and the covers, examination of the cuttings, transfer of rooted cuttings to baskets, placing of

baskets in hardeners, watering, removal from hardeners ; all are dispensed with in the new system. In addition, hidden costs of operating closed bins are appreciable ; these include the washing of sand medium and/or replacement of sawdust compost, washing and changing of calico bin covers, replacement of wooden frames on bins and the high water consumption. It is clear that appreciable savings in the cost of producing a rooted plant can be made by the use of the new technique.

One final question might be asked. How does growth of the rooted cutting in the cored basket compare with growth of cuttings basketed in the usual way? Over several months there has been little difference noticed and that, if anything, was in favour of the new system. However carefully rooted cuttings are transplanted into baskets some check in growth occurs even if the root system is undamaged. In the cored baskets no such check occurs and the roots develop undisturbed. There is no possibility of the twisted, uneven root distribution so often found in carelessly basketed plants.

The experimental unit here described can hold some 2,500 plants per setting, i.e., at eight settings per year on a six weeks cycle, some 20,000 plants. This figure would be increased if allowance is made for the removal of plants which have rooted at four and five weeks. The humidifier should cope with a greenhouse of twice the volume so that 40,000 cuttings a year could be set which, with 75% efficiency, would result in 30,000 plants ready for the field.

Summary

(1) A technique is described for producing rooted cacao cuttings in baskets in one operation at a substantial saving in cost as compared with the orthodox methods.

(2) The essential features are a glasshouse with a centrifugal humidifier maintaining 100% humidity and baskets with a central core of rooting medium surrounded by potting soil. The cutting is inserted into the core and the roots develop into the potting soil.

Reference

EVANS, H. (1953). Recent investigations on the propagation of cacao. *A report on cacao research, 1945-51*, p. 298. Imperial College of Tropical Agriculture, Trinidad.

APPENDIX (Technical Details)

Glasshouse.

Completely enclosed, glass sides, "windolite" roof (lighter than glass). Dimensions 20 ft. x 12 ft. x 8 ft., capacity some 2,500 baskets. Long side N—S to get maximum light through sides. Roof covered with camouflage netting to reduce light intensity to about 25%. Netting can be arranged to roll up to allow more light in dull weather.

Centrifugal Humidifier.

Bahnson type H. $\frac{1}{4}$ h.p. electric motor. Water requirement 6-8 gals. per hour at 20 lbs./sq. in.

Fittings.

Shelves 40 inches deep of aluminium angle strips, 20 inches or preferable 24 inches between shelves. Four shelves with ground level to give five tiers. Movable 2-3 inch wooden slats used as supports for the baskets of which six are placed in each row.

Baskets.

Core-former, a metal cylinder 9 inches long 2-2 $\frac{1}{2}$ inches diameter, potting soil lightly tamped round, cylinder withdrawn and dry composted sawdust put in, arranged in humidifier.

Cuttings.

Standard preparation, inserted about 3 inches deep into central core in baskets in humidifier.

Routine operation.

Humidifier on from 7 a.m. to 6 p.m. approximately. Turned off when raining. Baskets examined at twenty-eight days, rooted plants removed to shaded greenhouse. Examined again at thirty-five and forty-two days. Any failing to root by forty-two days gently pulled to see if roots have developed. If no roots, discarded, if rooting, placed in greenhouse and examined one week later for establishment.

A New Solar Fermentary

by

K. W. De Witt

THE Solar Fermentary was devised by McDonald (1935) for fermenting small samples of cacao. Its use has been reported several times since in experimental work. The apparatus consists of a thermally-insulated glass-topped box, the solar frame, which acts as a heat trap. The cacao is fermented in small boxes provided with holes for drainage, the heat generated by the fermentation being supplemented by that of the surrounding air heated by the sun, cooling at night being delayed by the insulation of the walls.

The solar fermentary described below was erected at River Estate in February, 1953, in order to ferment cacao from the field experiments for quality evaluation. Some small modifications have been made in McDonald's original design.

The solar frame (Fig. 1) consists of a double box of pitch-pine of external dimensions $108 \times 40 \times 39$ inches, internal dimensions $96 \times 28\frac{1}{2} \times 26\frac{1}{2}$ inches. The lid of the box is sloped downwards towards the front, which is 33 inches high. The insulating layer of sawdust between the walls of the box is 4 inches thick. An alternative and probably superior material, suggested by Mr. D. Perryman (Agricultural Department, Grenada), is coconut fibre, which has been used with success in the solar fermentary erected to this design in Grenada. The glass-paned lid is divided into three sections, the two outer ones being hinged at the rear, and provided with struts to support them in the raised position when required. The frame is supported 6 inches from the ground by beams.

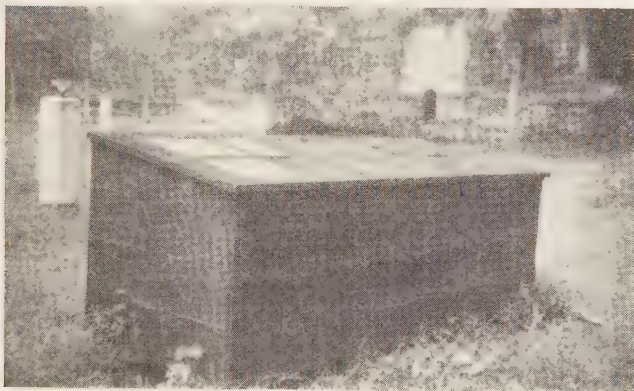


FIGURE 1
The solar fermentary.

All wooden parts of the frame are painted black. Inside the frame is a pair of flanged wooden rails, 12 inches apart, supported 9 inches from the bottom of the frame by legs and cross-members resting in grooved blocks. The six fermentation boxes fit between the flanges of the rails. Below the rails is a galvanised iron gutter, sloped towards a drainage hole at one end, to collect the sweatings. The rails, with their supports, and the gutter attached, can be lifted out of the frame (after unscrewing the centre section of the lid) for cleaning and repainting when required. The fermentation boxes (Fig. 2) are of plain pitch-pine, 12 inches cube externally, provided with lids. Drainage holes are drilled in the bottom only.

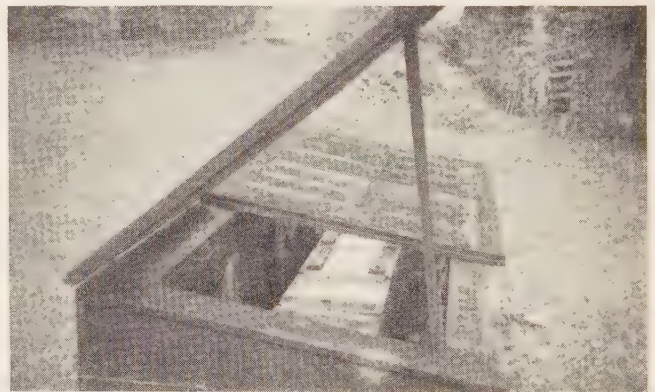


FIGURE 2
The solar fermentary, open, to show fermentation boxes.

The inside of the walls of the frame are hung with sacking, with the lower ends dipping into half kerosene tins filled with water. This appears to be sufficient to maintain the humidity at the necessary high level, provided that the sacking is thoroughly wetted before beginning a fermentation. It has not been found necessary to wet the insulating material as suggested by McDonald (*loc. cit.*). The daily maximum temperatures obtained inside the box are in the range 46° - 50° C. (115° - 122° F.).

The routine procedure used for the fermentation of clonal samples at River Estate is as follows. The boxes are filled with 30-35 lb. wet cacao to within 2 inches of the top, and covered with a layer of banana leaf $1\frac{1}{2}$ -2 inches thick. The covering is an essential part of the procedure and uniformity in fermentation is not obtained unless it is

carefully carried out. In particular, it is necessary to ensure that gaps are not left at the sides and corners of the box ; otherwise drying-out and mould growth occur. The lids are placed in position and the boxes lifted into the solar frame.

Turning is carried out on alternate days, by removing the boxes, transferring the beans to a basket, and mixing thoroughly before returning them to the frame. Care is necessary in replacing the banana leaf cover. On the seventh day of fermentation, the boxes are emptied on to the drying floor. Where the usual estate drying floor is used it is convenient to divide off a small area approximately four feet square, by laths laid on the floor, for each box. Alternatively, portable trays of the same size may be used. Sun-drying is carried out in the normal way, taking precautions to ensure that drying is not too rapid at first, by piling the beans fairly thickly. After 5-6 days, the beans are moistened and polished by hand, and the

drying then completed to the usual moisture content of approximately 8%. The final stages of drying may be carried out in an oven at 45°C. (113°F.).

The above procedure has yielded well-fermented cacao consistently in over thirty experiments, in which 21 different clones have been represented. So far, no clone has been found which requires special treatment. A similar model erected by the Department of Agriculture, Grenada, at Mount Horne Experimental Station, is also giving satisfactory results. It is clear that this method of fermentation is the most suitable one for the fermentation of small batches of wet beans, and might be of value to the smaller producers.

The design described above offers itself to co-operative enterprise, since the solar frame could be made of a length to accommodate a large number of boxes ; the advantages in fermenting individual batches separately are obvious.

Reference

- MCDONALD, J. A. (1935). A new method of curing small quantities of cacao. *Fifth report on cacao research*, p. 48. Imperial College of Tropical Agriculture, Trinidad.

The Susceptibility of some Imperial College Selections to Witches' Broom Disease

by

P. C. Holliday

Introduction

IMMUNITY or very high resistance to Witches' broom disease is only known in a few introduced cacao selections which came from the valley of the upper Amazon. Wide variations, however, have been found in Trinidad seedling trees in their production of fan and cushion brooms, although parallel differences in pod susceptibility were not apparent (Baker 1943a). Further differences in the behaviour of certain clones were shown by Baker and Crowdy (1943) and Baker (1943b) enabling an assessment to be made of the 21 clones in experiments CBR 1-4 at River Estate (Table I).

TABLE I

Experiments CRB 1-4. Susceptibility of clones to vegetative and cushion infection.

	Resistant	Fairly resistant	Susceptible	Very susceptible
FAN BROOMS	ICS 44, 45, 55, 91, 95	1, 2, 5, 6, 9, 12, 16, 53, 70, 98	3, 7, 8, 22	4, 60
CUSHION BROOMS	ICS 2, 6, 7, 8, 9, 22, 44, 91, 95, 98	1, 45, 55	3, 5, 12, 16, 70	4, 53, 60

All the clones, with the possible exception of ICS 1, have given consistent results from year to year. ICS 2

and 5, which were severely attacked by cacao beetle (*Steirastoma breve*), and ICS 7, which made very poor growth, may, however, be more susceptible than the table indicates.

Self-sterile clones tend to produce more cushion-brooms than self-fertile ones, because they are relatively freer in their flowering and cushion development (Table II).

The difference between the mean numbers of cushion-brooms produced by the self-fertile group and the self-sterile group is significant. The difference in the cushion-broom/fan-broom ratio is not significant. Table I shows that most clones give similar numbers of fan-brooms and of cushion-brooms.

Resistance to pod infection was also studied by Baker and Dale (1944) and Baker and Holliday (1953). The object of the present paper is to discuss the losses of pods in the River Estate experiments CRB 1-6. Apparent resistance may be nothing but disease avoidance, by which is meant the capacity of a tree to produce much of its fruit in the drier months of the year when infection is low. Some of the clones showed this capacity, usual in young cacao, when they were young, but it decreases rapidly with increasing age (Baker *et al.* 1953), and has had no effect on the results here presented. The few clones that do set much of their crop, even as fairly mature trees, in the dry season, will be discussed later. All percentages have been transformed before analysis by the angular transformation (Snedecor 1946).

TABLE II

Experiments CRB 1-4. The numbers of cushion-brooms in self-fertile and self-sterile clones per tree per year.

Self-sterile ICS	2	3	4	5	12	16	22	53	60				Means
Cushion-brooms ...	2.7	19.6	22.1	21.9	18.1	9.9	2.0	30.4	46.2				19.2*
Cushion/Fan-brooms	0.44	0.53	0.48	0.86	1.00	0.55	0.10	1.92	1.65				0.84+
Self-fertile ICS	1	6	7	8	9	44	45	55	70	91	95	98	
Cushion-brooms ...	16.0	4.2	3.6	3.9	2.9	2.2	8.6	7.7	8.4	3.1	4.3	2.1	5.6*
Cushion/Fan-brooms	0.54	0.12	0.15	0.11	0.18	0.49	0.78	1.16	1.02	0.69	0.78	0.12	0.51+

S.E. of difference between two means $\pm 4.7^*$ and $\pm 0.22^+$.

Experiment CRB I (ICS 1, 3, 4, 5, 6 and 8)

ICS 1 and 6 are easily the least susceptible clones, having lost significantly fewer pods each season. ICS 3 and 5 are the most susceptible and both ICS 4 and 8 must be rated as intermediate. In June, 1947, pen manure augmented with inorganic fertilisers was applied to this experiment (Dodds *et al.* 1951) and in the following season there was a significant increase of disease on the manured plots (Table IV).

TABLE III
Experiment CRB I. Pod infection.

Season	ICS 1	ICS 3	ICS 4	ICS 5	ICS 6	ICS 8	S.E. Clone difference	Means
1947-48	7.15 (2.0)	19.69 (19.6)	22.97 (15.4)	32.85 (30.7)	11.37 (4.5)	22.22 (16.4)	± 2.93 —	— (12.1)
1948-49	19.85 (14.2)	46.20 (52.5)	34.76 (35.1)	32.46 (41.3)	22.56 (15.8)	30.69 (28.9)	± 2.48 —	— (26.6)
1949-50	20.04 (13.2)	40.99 (48.3)	37.20 (39.7)	41.48 (49.3)	21.67 (14.3)	35.88 (30.9)	± 2.47 —	— (30.9)
Means	...	(9.8)	(30.8)	(41.3)	(11.6)	(27.1)	—	—

Figures are means per plot of 8 trees of each clone.
Without brackets transformed percentages.
Within brackets actual percentages.

TABLE IV
Experiment CRB I. Pod infection in manured (M) and unmanured trees (—M).

Season	ICS 1 M —M	ICS 3 M —M	ICS 4 M —M	ICS 5 M —M	ICS 6 M —M	ICS 8 M —M	SE M— (—M) within clones	Means M —M	SE M— (—M) means
1947-48	6.44 (1.7)	17.02 (16.7)	23.44 (15.9)	32.30 (30.0)	13.49 (6.3)	23.89 (17.4)	± 2.55 —	19.60 (12.5)	± 1.04 —
1948-49	21.37 (15.2)	47.04 (53.3)	36.19 (36.4)	40.03* (46.3)	21.24 (14.2)	35.75* (35.3)	± 3.49 —	33.60* (29.6)	± 1.55 —
1949-50	19.66 (13.4)	43.38 (49.3)	35.90 (38.3)	43.92 (49.5)	22.12 (15.6)	34.87 (33.3)	± 2.76 —	33.31 (31.2)	± 1.18 —
Means	(10.4)	(46.0)	(30.8)	(43.9)	(12.4)	(28.5)	—	(25.2)	(22.5)

Figures are means per plot of 8 trees of each clone.
Without brackets transformed percentages.

Within brackets actual percentages.
* Indicates a significant difference.

Experiment CRB 2 (ICS 1, 7, 16, 22, 45 and 53)

TABLE V
Experiment CRB 2. Pod infection.

Season	ICS 1	ICS 7	ICS 16	ICS 22	ICS 45	ICS 53	S.E. Clone difference	Means
1947-48 ...	13.60 (6.0)	19.55 (12.1)	33.79 (30.8)	23.49 (17.0)	21.41 (14.5)	21.66 (14.0)	± 1.82 —	— (16.2)
1948-49 ...	25.66 (18.9)	41.24 (45.0)	41.22 (43.9)	30.14 (26.3)	10.91 (6.6)	19.77 (12.0)	± 3.38 —	— (29.4)
1949-50 ...	25.91 (19.3)	39.29 (39.2)	52.92 (63.4)	34.38 (31.3)	32.86 (29.5)	38.97 (39.0)	± 1.95 —	— (37.4)
Means ...	(14.7)	(35.8)	(47.0)	(25.0)	(19.0)	(26.8)	—	—

Figures are means per plot of 16 trees of each clone.
Without brackets transformed percentages.
Within brackets actual percentages.

ICS 1 is again the least susceptible clone. ICS 45, which is not very consistent from season to season, is significantly less susceptible than ICS 1 in one year (1948-49). ICS 16 is the worst clone and is very

susceptible, but was equalled by ICS 7 in 1948-49. The other two clones, ICS 22 and 53 must be rated as moderately susceptible.

Experiment CRB 3 (ICS 1, 2, 9, 12, 60 and 98)

TABLE VI
Experiment CRB 3. Pod infection.

Season	ICS 1	ICS 2	ICS 9	ICS 12	ICS 60	ICS 98	S.E. Clone difference	Means
1947-48 ...	10.90 (3.9)	17.45 (9.7)	28.50 (23.4)	11.57 (6.3)	13.25 (6.3)	13.21 (6.3)	± 2.74 —	— (9.9)
1948-49 ...	17.21 (10.1)	16.48 (9.7)	35.98 (34.4)	13.74 (14.7)	22.95 (17.6)	18.03 (13.01)	± 2.72 —	— (16.1)
1949-50 ...	18.59 (10.6)	29.24 (24.5)	43.90 (48.0)	22.26 (20.1)	19.54 (11.8)	22.42 (14.9)	± 1.77 —	— (21.8)
Means ...	(8.0)	(16.1)	(35.4)	(13.3)	(10.5)	(11.4)	—	—

Figures are means per plot of 8 trees of each clone.
Without brackets transformed percentages.
Within brackets actual percentages.

There is only one highly susceptible clone—ICS 9, and it always has significantly more infection than all the others. The least susceptible clone is again ICS 1, but ICS 12, 60 and 98 are almost as good. Manurial dressings

were also applied to this experiment in 1947, but instead of pen-manure a mulch of "cut bush" was used. No significant differences of infection between manured and unmanured plots have shown up.

Experiment CRB 4 (ICS 1, 44, 55, 70, 91 and 95)

TABLE VII

Experiment CRB 4. Pod infection.

Season	ICS 1	ICS 44	ICS 55	ICS 70	ICS 91	ICS 95	S.E. Clone difference	Means
1947-48 ...	8.66 (12.4)	15.19 (7.3)	8.03 (2.4)	19.52 (10.9)	11.44 (4.4)	4.97 (1.0)	± 2.09 —	— (4.1)
1948-49 ...	14.60 (7.0)	14.13 (5.9)	12.41 (5.9)	18.23 (11.5)	10.17 (5.2)	7.45 (2.2)	± 2.05 —	— (6.3)
1949-50 ...	15.38 (7.5)	22.09 (14.7)	25.13 (16.7)	33.37 (31.3)	16.16 (9.2)	10.39 (3.3)	± 2.04 —	— (12.0)
Means ...	(5.4)	(9.9)	(9.6)	(18.1)	(6.4)	(2.1)	—	—

Figures are means per plot of 16 trees of each clone.
Without brackets transformed percentages.
Within brackets actual percentages.

None of the clones is very susceptible, but ICS 70 was easily the worst each season.

ICS 91 is of the same order of susceptibility as ICS 1,

but ICS 95 has been consistently better than ICS 1 and significantly so in two seasons. ICS 44 and 45 are intermediate between ICS 1 and 70.

Experiment CRB 5 (ICS 12, 38, 45, 54, 85 and 101)

TABLE VIII

Experiment CRB 5. Pod infection.

Season	ICS 12	ICS 38	ICS 45	ICS 54	ICS 85	ICS 101	S.E. Clone difference	Means
1950-51 ...	16.01 (7.8)	4.46 (5.3)	13.28 (5.1)	37.07 (36.4)	25.33 (18.0)	16.31 (8.9)	± 2.07 —	— (18.3)
1951-52 ...	18.21 (11.6)	16.52 (17.4)	10.95 (3.9)	29.58 (24.5)	22.19 (14.3)	11.66 (5.6)	± 3.54 —	— (13.0)
1952-53 ...	12.50 (5.3)	15.52 (8.3)	8.82 (2.6)	20.58 (12.7)	16.98 (9.9)	5.56 (2.5)	± 2.84 —	— (8.4)
Means ...	(7.8)	(10.3)	(3.9)	(25.1)	(14.1)	(5.7)	—	—

Figures are means per lot of 16 trees of each clone.
Without brackets transformed percentages.
Within brackets actual percentages.

These are all Criollo clones so ICS 1 cannot be used as a standard. However, some degree of comparison is achieved through ICS 12, which in CRB 3 is of the same order of resistance as ICS 1.

ICS 54 is the most susceptible clone, but in one season ICS 38 and 85 are nearly as bad. The least susceptible clones in this experiment are ICS 12, 45 and 101, and there is no significant difference between them.

Experiment CRB 6 (ICS 1, 25, 31, 32, 36 and 67)

TABLE IX
Experiment CRB 6, Pod infection.

Season	ICS 1	ICS 25	ICS 31	ICS 32	ICS 36	ICS 67	S.E. Clone difference	Means
1949-50 ...	18.64 (10.5)	30.61 (24.0)	30.93 (27.5)	25.31 (17.8)	40.59 (42.6)	30.35 (24.0)	± 2.42 —	— (22.5)
1950-51 ...	21.66 (13.6)	32.46 (28.4)	27.55 (20.2)	25.01 (17.7)	38.65 (38.8)	35.95 (33.2)	± 2.87 —	— (23.1)
1951-52 ...	28.57 (23.0)	39.67 (41.2)	28.98 (22.1)	26.19 (19.0)	44.56 (49.1)	44.52 (48.2)	± 2.92 —	— (31.2)
Means ...	(16.5)	(33.7)	(22.5)	(18.2)	(43.5)	(37.7)	—	—

Figures are means per plot of 16 trees of each clone.
Without brackets transformed percentages.
Within brackets actual percentages.

Once more ICS 1 is clearly the least susceptible clone, ICS 32 sometimes approaching it. ICS 25, 67 and 36 especially, are very susceptible.

The information from all the above six experiments is summarised as Table X.

TABLE X
Experiments CRB 1-6. Susceptibility of clones to pod infection.

Resistant	Fairly resistant	Susceptible	Very susceptible
ICS 1, 6, 12, 38, 45, 60, 91, 95, 98, 101	ICS 2, 31, 32, 44, 55, 85	ICS 7, 8, 22, 25, 53, 54, 67, 70	I.C.S. 3, 4, 5, 9, 16, 36

Discussion

On page 58 "disease avoidance" was mentioned. The clones which set a high proportion of their crop in the dry weather are ICS 5, 9, 16, 53 and 95, but in spite of doing so the first four have lost a high percentage of their pods from Witches' broom disease to which they are very susceptible. ICS 95, on the other hand, has regularly lost fewer pods than ICS 1 and must be rated as one of our most resistant clones.

Attempts to correlate pod infection with fan and cushion-broom formation indicate that in general a clone producing many fan and cushion-brooms tends to have a high pod infection. Certain clones show a negative correlation in this respect, but an attempt at assessing over-all susceptibility has been made in Table XI.

TABLE XI
Experiments CRB 1-4. Susceptibility of clones to pod, cushion and vegetative infection.

Resistant	Fairly Resistant	Susceptible	Very Susceptible
ICS 6, 45, 91, 95, 98	ICS 1, 2, 44, 55	ICS 5, 7, 8, 12, 22, 70	ICS 3, 4, 9, 16, 53, 60

It is notable that three of the clones here placed in the "resistant" category, ICS 91, 95 and 98, were originally selected as large vigorous trees, producing many pods, which failed to reach the selection level for pod-size and bean-weight. There is an indication here that the "higher quality" cacaos may be more susceptible to the disease.

The differences in susceptibility between the clones are great enough to be taken into account commercially as it would be inadvisable to plant the very susceptible clones in areas where the disease is likely to be severe. ICS 95 is outstandingly resistant; it was selected without reference to disease resistance and may be taken as an indication that valuable resistant trees certainly occur in Trinidad cacao fields.

The fact that a clone which forms few vegetative or cushion-brooms is usually fairly resistant to pod infection indicates that the factors controlling infection are probably physiological rather than of a simple morphological nature. The anomalous behaviour of clones like ICS 9, which is very susceptible to pod infection, but produces few fan or cushion-brooms, remains to be explained. It is, however, important to note that, for field tests, data on pod infection alone—more conveniently recorded than broom counts—will usually give reliable information for the whole tree.

In one experiment percentage pod losses were increased by manuring (although *total* yield was increased much more). This effect of manure on disease has been noted elsewhere in this report (p. 81). The effect of buddings and cuttings on the disease is usually without significance, but a few significant interactions, difficult to explain and requiring confirmation, have occurred.

Summary

Three years' records at River Estate show that differences in susceptibility to Witches' broom disease exist among the ICS clones.

Usually those clones most susceptible to pod infection will produce most fan and cushion-brooms, but anomalous clones, such as ICS 9, exist.

The most resistant clones, suitable for growing in areas where the incidence of the disease is expected to be heavy, are ICS 6, 45, 91, 95 and 98. Here only resistance to disease is considered and cultivation of these clones may still be ruled out for other reasons.

ICS 3, 4, 9, 16, 53 and 60 are very susceptible, and even if otherwise desirable, should not be grown in bad Witches' broom disease areas.

There are indications that manuring, while markedly increasing total yields, may also increase the percentage losses of pods due to the disease.

Acknowledgments

The writer is indebted to Prof. R. E. D. Baker for suggesting a continuation of this line of enquiry and to Mr. F. W. Cope, for advice on the statistical analysis.

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Spraying against Witches' Broom Disease

by

P. C. Holliday

THE early work on the control of Witches' broom disease by spraying has been summarised by Baker and Crowdy (1944). It was inconclusive, but Dale (1946) suggested that further trials might be warranted if spraying was restricted to the pods. Desrosiers and Balaños (1952) used sprays in a different approach, by treating brooms to prevent sporophore growth. Sodium pentachlorophenate and dinitro-o-cresol were both effective at non-phytotoxic concentrations. Thorold (1953) reduced the incidence of fan brooms and of infected pods in Trinidad with monthly applications of 1% Bordeaux.

In Trinidad the most serious losses occur from October to March (Table I). Pods do not show symptoms until three months after infection Dale (1946), therefore, spraying should begin in late June, when fruit setting starts, and continue until December. This period, when infection is at its maximum, coincides with the fruit set of the main harvest. The three experiments to be described have already been briefly referred to by Dale (1953).

Methods

Compressed-air, hand-pumped, spraying units with a 2½ gallons working capacity were employed. The nozzle gave a fine cone-like mist-spray at the rate of 8 gallons an

hour. On the clonal trees used all the pods could be sprayed satisfactorily, but the foliage was not treated. No attempt was made to apply a fixed quantity per acre; the amount varied from 15-50 gallons according to the month, the variation being due to the size and number of pods. Records began three months after the first application and ended three months after the last. Infection by *Phytophthora palmivora* (Butl.) was noted.

Experiment 1 (1950-51)

The trees used were the clone ICS 1 planted in 1938-39 as fan cuttings at 12 feet × 12 feet spacing with immortal shade. They form part of a field at River Estate in which brooms are also removed twice a year.

There were three treatments: Bordeaux (2%), Perenox (cuprous oxide) applied at the equivalent of 1% Bordeaux, and no spray. The trees were split into eight randomised blocks each of three plots of six trees, making 48 trees for each treatment. Spraying was begun on 27th June and continued once every four weeks until 15th December. The percentages of Witches' broom pods were calculated on total pods reaped in each plot and for analysis they were transformed as the square roots Cochrane (1938). The results are given in Table II.

TABLE I
Percentage witches' broom directly infected pods on 96 trees of ICS 1
in Experiment CRB 1 at River Estate.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1943 ...	32	59	—	24	8	—	1	4	—	60	7	0
1944 ...	14	62	32	18	10	0	0	—	0*	21	24	19
1945 ...	25	46	24	3	2	0	0	—	0*	0*	13	27
1946 ...	4	4	14	4	4	0	0	0*	—	—	23	11
1947 ...	4	16	15	1	0	3	0	—	0*	—	—	15
1948 ...	4	1	0	0	0	0	0	0*	—	—	11	42
1949 ...	26	14	8	1	0	0	0	0*	—	33*	64	10
Mean ...	15.6	28.9	13.3	7.3	3.4	0.4	0.1	0.6	0	16.3	20.3	17.7

— No crop picked.

* Less than 10 pods picked.

TABLE II

Experiment 1. The effect of treatment by spraying on the incidence of pod infection as the mean number of pods per plot.

Treatment	Total	Healthy	Witches' broom (WB)	% WB	Trans-formed % WB
Bordeaux	136.8	130.5	1.9	1.4	.99
Perenox	151.5	140.1	3.4	2.2	1.46
No spray	173.4	156.3	7.9	4.6	2.07
S.E. difference between two means	—	±13.84	—	—	±.305

Control by Bordeaux compared with no spray is significant. There was no significant control by Perenox and no significant difference in the number of healthy pods between treatments. The reduction in the number of healthy pods on the Bordeaux-treated trees approaches significance.

Experiment 2 (1951-52)

Although incidence of disease was very low in the field used in Experiment 1 the same trees were used again in 1951-52. There were four treatments: Bordeaux 1% and 0.5%, Perenox (equivalent to 1% Bordeaux), and no spray. To the Perenox was added, as a sticker, 0.1% Albolineum No. 1 (an emulsion containing 80% refined mineral oil). The trees were split into six randomised blocks each of four plots of six trees, giving 36 trees for each treatment. Spraying began on 25th July and continued once every four weeks until 12th December. The results are given in Table III; analysis was carried out as for Experiment 1.

TABLE III

Experiment 2. The effect of treatment by spraying on the incidence of pod infection as the mean number of pods per plot.

Treatment	Total	Healthy	Witches' broom (WB)	% WB	Trans-formed % WB
Bordeaux 1%	173.8	156.3	15.0	8.6	2.78
Bordeaux 0.5%	167.0	146.3	17.2	10.3	3.19
Perenox	170.5	151.7	15.0	8.8	2.91
No spray	185.0	156.7	24.7	13.4	3.51
S.E. difference between two means	—	±12.95	—	—	±.338

Significant control was shown only by 1% Bordeaux. There was no significant difference between treatments in the number of healthy pods reaped, the incidence of the disease being far too low. The Perenox was appreciably better than 0.5% Bordeaux.

Experiment 3 (1952-53)

This was carried out at Non Pareil Estate, which is in a higher rainfall area than River Estate and, therefore, was expected to have a heavier incidence of the disease. The trees used were mixed clones with immortelle shade. Although they were quite uniform for age it became clear later that their yields and probably their susceptibility to the disease were very variable. Brooms are removed regularly in this field.

There were six treatments: Perenox, Blitox (copper oxychloride), Sulfinette (lime sulphur), Fernide (tetramethyl thiuram disulphide), Ziram (zinc dimethyl dithiocarbamate) and no spray. The sprays contained 0.25% active material and 0.1% Albolineum No. 1. The two copper fungicides were comparable in concentration to 1% Bordeaux. Five blocks each contained six plots of six trees each to which the treatments were assigned at random.

TABLE IV

Experiment 3. The effect of treatment by spraying on the incidence of pod infection as the mean number of pods per plot.

Treatment	Total	Healthy (H)	% H	Trans-formed % H	Witches' broom (WB)	% WB	Trans-formed % WB
Perenox ...	115.8	38.8	33.5	40.78	12	10.3	14.76
Blitox ...	116.8	74.2	63.5	52.24	13	11.1	19.33
Sulfinette ...	131.6	43.8	33.3	38.24	13	9.8	17.67
Fernide ...	149.8	52.8	35.2	36.57	23	15.3	22.87
Ziram ...	124.2	40.2	32.4	36.77	17	13.7	21.42
No spray ...	79.2	29.8	37.6	40.87	15	19.0	22.40
S.E. difference between two means ...	± 25.84	—	—	± 5.585	—	—	± 4.328

Spraying began on 21st July and continued once every four weeks until 10th November. The results (Table IV) are from records from the end of October to the end of February. For analysis the percentages have been transformed by the angular transformation as given by Snedecor (1946).

None of the treatments gave significantly less pod infection though Perenox was nearly significantly better than no spray. The discrepancy in Table IV between total pods and the healthy and Witches' broom pods is largely made up of pods attacked by *Phytophthora palmivora* (Butl.). The incidence of black pod was higher than Witches' broom and the effect of the fungicides on the former disease is given for October and November, when infection was highest, in Table V. The angular transformation has been used for analysis.

TABLE V

Experiment 3. The effect of treatment by spraying on the incidence of black pod disease as mean numbers of pods per plot.

Treatment	Total	Black pods (BP)	% BP	Transformed % BP
Perenox ...	56.4	11.8	20.9	25.60*
Blitox ...	41.0	8.2	20.0	28.36
Sulfnette ...	70.4	28.4	40.3	38.97
Fernide ...	59.8	29.6	49.6	43.10
Ziram ...	59.2	21.0	35.5	34.87
No spray ...	44.2	21.0	47.5	39.14

* S.E. difference between two means = ± 4.91 .

Significant control was given by the two copper sprays. The other treatments are not significantly different from the control plots.

Discussion

Bordeaux was slightly superior to Perenox and there was little difference in the control given by the two proprietary copper fungicides. The decrease in the number of healthy pods in Experiment 1 on the Bordeaux plots may mean it is phytotoxic at this concentration. Lime sulphur gave surprisingly good results at Non Pareil against *Marasmius perniciosus*, but it can have less practical application than copper for, as might be expected, it gave no control of the *Phytophthora*. The two organic fungicides had little or no effect on either fungus under the Non Pareil conditions. The absence of significant control of Witches' broom in the third experiment was probably due to tree variability. The fungicides were very inconsistent from plot to plot, considerably inflating the error in the analysis.

At River Estate Thorold (1953) demonstrated a decrease of 60% in Witches' broom pod infection with monthly applications of 1% Bordeaux over twenty-two months (twenty applications). In the first two trials (River Estate) Bordeaux reduced it by 70% and by 36%. At Non Pareil Perenox reduced it by 46%.

It is estimated that unless the pod infection rate is at least 15-20% on a field yielding 800 lb. of dry cacao, or more, per acre spraying is unlikely to be profitable to control Witches' broom alone. In any event brooms still have to be removed and on the less susceptible clones the

disease can be controlled by this method alone, keeping losses to less than 15% even in high rainfall areas.

Nevertheless, as pointed out by Dale (1953), where losses through black pod are also severe a spray schedule to control both diseases on the pods might be devised because the times when both are serious coincide. At Non Pareil from October to February on the unsprayed plots 50.5% of the crop was infected by Witches' broom or black pod; on those sprayed with Perenox 28.3% and with Blitox 21.1%. The Blitox sprayed trees gave more healthy pods in the total harvest from October to March. The percentage of healthy pods was: no spray 37.9; Perenox 46.1; and Blitox 63.5 (and see Table IV). The use of Blitox in further experiments designed to determine the optimum frequency and times of application to control both Witches' broom and black pod infection on the fruit would be worth while.

Summary

Significant control of Witches' broom disease during the six months when infection is highest was given by Bordeaux with six or seven monthly applications from June or July to December.

Monthly applications from July to November of Blitox (copper oxychloride) and Perenox (cuprous oxide) gave good control of Witches' broom and black pod. Sulfnette (lime sulphur) gave control of Witches' broom but not of black pod. Tetra-methyl thiuram disulphide (Fernide) and zinc dimethyl dithiocarbamate (Ziram) gave little or no control of either disease.

A spray programme to control both *Marasmius perniciosus* and *Phytophthora palmivora* simultaneously could be devised for Trinidad and might be economic. Since brooms must still be removed, it is unlikely that control of Witches' broom disease alone is worth while except in fields giving 800 lb. of dry cacao, or more, per acre and where losses of at least 15% are expected.

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Notes on Minor Insect Pests of Cacao in Trinidad

PART 2. LEPIDOPTERA (BUTTERFLIES AND MOTHS)

by

T. W. Kirkpatrick

ALTHOUGH only one of the numerous butterfly and moth caterpillars that feed on cacao has ever been found to be sufficiently abundant to cause appreciable injury, in view of the interest taken in the order Lepidoptera and the fact that very little has been recorded about the early stages of any Trinidad species, it has been thought worth while to give a short account of all except for a few that have been observed only once or twice.

It is usually considered that the butterflies, at least, of Trinidad are fairly well known, yet of twelve species the larvæ of which have been taken feeding on cacao four are not represented in the collection made over a period of many years by the late Sir Norman Lamont, nor are they mentioned in Kaye's (1921) catalogue.

I am indebted to Dr. W. J. Hall and the staff of the Commonwealth Institute of Entomology for the identification of many of the Lepidoptera and all the parasites mentioned.

Except for the Psychidæ (bag-worms) which are most often found feeding on hardened leaves, all the leaf-eating caterpillars feed only on flush leaves. It is probable that this is to some extent responsible for keeping the populations at low levels: it must often happen that the leaves on which a caterpillar is feeding harden before it is full-fed, and that it is unable to find new flush leaves, or that a female cannot find suitable flush on which to oviposit. However, many of the species are doubtless only casual feeders on cacao, though alternative host plants have only been recorded for a few of them.

The amount of damage done by insects that eat immature leaves varies inversely with the age of the leaf since the diameter of a hole increases in direct proportion to the length of a leaf. If, for instance, a round hole 1 cm. in diameter, and, therefore, with an area of about 0.78 cm.², is made in a cacao leaf 5 cm. long, by the time the leaf is 25 cm. long the hole will have a diameter of 5 cm. and an area of nearly 20 cm.²

Leaf Eaters

Family Pyraustidæ.

Sylepta prorogata Hampson. Cacao leaf tyer. Larva* about 20 mm. long, dirty green, shining, the head yellowish. The two apical joints of the thoracic legs shining black, abdominal prolegs pale yellow and very slender. Body sparsely covered with fine pale hairs mostly not much

longer than half the diameter of the body. The earlier instars of the larva are pale yellow. The first instar larva spins a certain amount of silk but does not roll a leaf. The later instars either feed from inside a rolled leaf or spin two or more leaves together. Several larvæ are often found in one such "nest." Pupation takes place within a rolled leaf which is completely closed. Larval period 14-16 days, pupa 6-7 days. Generally distributed and common throughout the year; perhaps rather more often on chupons than on canopy flush. This species has not been observed to cause appreciable damage in Trinidad, but according to Bondar (1939) it is at times a serious pest in Bahia, Brazil.

Family Pterophoridæ.

Oxyptilus sp. Cacao Plume moth. (Previously recorded (Lamont and Callan, 1950) as *Platyptilia* sp.). Larva about 13 mm. long, elongate, pale yellow, becoming dull green on the dorsum when full grown, rather sparsely clothed with long white hairs which are nearly twice as long as the diameter of the body, and with much shorter black truncate hairs. Abdominal legs long and slender. Several larvæ may often be found on one flush leaf, they eat roundish holes in the centre of the leaf near the midrib, though last-instar larvæ may eat almost the whole leaf. Unlike most Lepidopterous larvæ they often feed from the upper surface of a leaf.

Pupa pale green, 7 mm. long, elongate and sharply pointed caudad, attached by the cremaster to the midrib of a leaf or to a shoot. On the anterior half of the dorsum there is a double row of short rasp-like teeth, most of which are tipped with black and bear a minute somewhat capitate black hair. Duration of the larval stage about 12 days, of the pupa 5 days. Common everywhere throughout the year. The larva is very frequently parasitised by the Tachinid *Actia panamensis* Curran, one parasite developing in each caterpillar, which dies before pupating.

Family Psychidæ. Bag-worms.

The larvæ of this family construct portable cases of leaves and twigs bound together with silk; pupation takes place in the case. The males emerge as ordinary moths, but the females are degenerate, always wingless and, in *Oiketicus* and some other genera, without mouth parts, legs or antennæ. They never leave the larval case and do not even get completely free from the pupa.

* Descriptions, unless otherwise stated, are of fully grown larvæ.

**Oiketicus kirbyi* Guilding. The larval case of the male is about 50-60 mm. in length, made of bits of leaf and twigs, many of which are built in transversely. It is more or less covered, especially near the middle, with a mat of coarse brown silk. The case of the female may be up to 100 mm. long. The larva takes about six months to develop and the pupal period is about two months. This species is not common in Trinidad.

Another Psychid, of an undetermined genus, makes a case only some 20 mm. in length, mainly of fragments of leaves with no silk externally. The duration of the larval period has not been determined, but is probably over four months; the pupal stage lasts one month. This species is quite common; it has also been found on Hibiscus.

Family Cochlidæ. Slug caterpillars.

Euprosteria eleasa Dyar. Larva about 18 mm. long and, including the projecting lateral scoli, 12 mm. wide; broadly oval, pale green, with a double dorsal carina having a pair of small purple spots on each segment. There is a pair of lateral spine-bearing scoli on each segment and also a pair of rather smaller outwardly projecting sub-dorsal scoli, which are erectile. On the thoracic segments the lateral scoli are pink. Thoracic legs minute, abdominal prolegs absent. Pupa in a spherical brown cocoon. Duration of larval stage about one month, pupa 18-20 days.

The larvæ are parasitised by an Ichneumonid of a genus near *Charops* and also by a Tachinid which, however, has not been bred to maturity.

Occasional on cacao; it also feeds on coconut (Lamont and Callan, 1950).

Phobetron hipparchia Cramer. Larva about 35 mm. long, width of actual body 10 mm., across lateral processes 35 mm. Head very small, retractile under the hood-like fleshy lobes of the prothorax. Thoracic legs minute, abdominal prolegs absent. Mesothorax with three pairs of tubercles bearing short fulvous hairs, remainder of dorsum covered with a dense mat of sub-plumose hairs arising from black spherical tubercles, the hairs are black with pale brown tips except on the 2nd and 4th abdominal segments, on which the tips are also black. Six pairs of elongate flat lateral processes arise from the metathorax, the 1st, 2nd, 4th, 6th and 7th abdominal segments. These processes are thin-walled sacs filled with haemolymph and covered with a dense woolly mat of short pubescent dull black hairs, and a few much longer pale simple hairs. The metathoracic processes have some fulvous hairs beneath. They are somewhat curved backwards, and pointed at the apex. Those on the 2nd, 4th and 6th abdominal segments are about 15 mm. long, on the 1st and 7th about 10 mm., and on the mesothorax 4 mm. At the sides of the body below the processes there is on each segment a verruca bearing numerous black hairs with pale tips, and on the 3rd, 4th and 5th abdominal segments there is a smaller verruca just above the larger one, clothed with short jet black hairs, with a few white hairs between the two verrucæ. In the penultimate instar the body hairs are mainly fulvous, but darker reddish-brown on the 2nd and 4th abdominal segments, and the processes are covered with fawn-coloured hairs. The processes are easily broken off, the loss of one or two appears to do no harm, but larvæ from which all were removed died. The general appearance of this remarkable

larva is that of a large hairy spider. The pupa is formed within the cast skin of the last larval instar. The larval period is probably about five weeks and the pupal 18-20 days.

This curious caterpillar is only occasional on cacao, but on young citrus plants it is sometimes abundant enough to cause severe defoliation. It has also been seen on Canna.

Family Dalceridæ.

Acraga ochracea Walk. Larva oval, about 15 mm. long and 7 mm. broad. Head small, retractile, yellow; thoracic legs very short, abdominal prolegs absent. Body quite hairless, white, showing bluish through the integument; each segment with three pairs of viscous jelly-like conical protuberances, rather irregular in shape. These are easily detached without apparent injury; a small larva has been seen eating the "jelly" of another, which successfully completed its development. The earlier instars of the larva are pale yellow. Cocoon of pale yellow silk with a patch of red silk at each end and round the hole left in the middle of the dorsal surface by which the adult emerges. Larval period about 15 days; from spinning cocoon to emergence of adult 10 days.

The larva is not uncommon, but is frequently parasitised by *Pararhinactia parva* Towns. The larvæ of this Tachinid emerge from the prepupa after the cocoon has been spun, pupate immediately and become adult in 9-10 days. As many as 9 larvæ have emerged from a single host though 4 or 5 is more usual.

Family Saturniidæ.

Automeris erisichton Bois. Larva about 60 mm. long, bright grass green, the abdomen with a cream-coloured lateral stripe narrowly bordered above with crimson. Each segment with three pairs of bright green scoli bearing numerous urticating spines; the lateral scoli, situated just below the lateral stripe, smaller than the dorsal and sub-dorsal ones, which are nearly as long as the diameter of the body. Thoracic legs crimson, abdominal prolegs green with a crimson spot on the outer side just above the large slate-grey planta. Pupa in a rather thin but tough cocoon spun between leaves.

Only larvæ at least half grown have been found on cacao: the normal host plant is probably *Erythrina*, from which larvæ occasionally drop on to cacao, on which they readily complete their development.

Family Erycinidæ.

**Calodeta lypera* Bates. Larva about 20 mm. long, brown, much suffused with greyish white at the sides, with a lateral fringe of long fine white hairs; a pinkish brown dorsal stripe with a pair of small verrucæ on each segment, each bearing 5-7 stiff brown hairs. The whole body above is thickly covered with minute spherical drops of exudatory matter, these are mostly white but some pink or brown according to the underlying body colour. Pupa bright green. Larval period about three weeks, pupa 7-8 days. Uncommon, only noticed in the dry season.

**Emesis cerea* (L.). Larva about 18 mm. long, apple green, yellowish on dorsum of 5th abdominal segment, rather darker green dorsal and subdorsal stripes. Each segment with a pair of dorsal and subdorsal verrucæ bearing a tuft of 20-30 pale hairs. Pupa pale green, thinly clothed with fine white hairs. Before pupating the larva spins two transverse rows each of several strands of silk, about one inch apart, and pupates between them. Dura-

* Species marked with an asterisk are apparently new to the published Lepidopterous fauna of Trinidad.

tion of larval period unknown, pupa 6-7 days. Only seen in the dry season.

Emesis mandana (Cram.). Larva 45 mm. in length, the head black with W-shaped yellow lines; body colour red, each segment with two pairs of bright scarlet verrucae bearing a rosette of 15-25 stiff black hairs. In the early instars the body is yellowish orange at the sides and black on the dorsum and the verrucae are mainly black. Pupa yellow, boldly marked with black spots and longitudinal stripes, in a slight cocoon. Larval period about three weeks, pupa 9-10 days. Uncommon on cacao, has also been recorded from cashew.

Nymphidium calyce Feld. Larva about 25 mm. long, the head brown; prothorax whitish on dorsum, dark brown at the sides, with two blunt horns projecting forwards and outwards, each with a pair of terminal bristles; remainder of body dull green except that the dorsum of the meso- and meta-thorax is light brown with a darker central stripe, the dorsum of the first abdominal segment is dark brown and there is a small median dark brown spot on the posterior margin of the 2nd to 7th segments, and the dorsum of the 8th segment is mainly light brown. Body almost hairless except for a lateral fringe. Larval stage three weeks, pupal 8-10 days. Throughout the year, but commoner in the dry season.

Theope eudocia Doubl. Larva 15 mm. long, the head brown with an inverted white Y-shaped mark. Body mainly apple green with a rather darker dorsal stripe, covered with very minute hairs, mostly pale but a few black, and a lateral fringe of longer pale hairs. Prothorax with a bunch of nearly 100 pear-shaped protuberances on the dorsum which project forwards over the head; some of the protuberances are black and some brown and they are of varying sizes, with several long pale hairs among them. Mesothorax with purplish sub-dorsal stripes, small purple sub-dorsal spots at the posterior margin of the metathorax and first seven abdominal segments, a purple dorsal stripe on the 7th, 8th and 9th segments, which on the 8th is expanded laterally to form a + shaped mark. Dorsum of the 9th segment in the form of a flat saddle-shaped plate completely overhanging the 10th segment. Larval period about 25 days, pupa 11 days. The larva is invariably attended by ants.

Guppy (1914) states that the larvæ of this and the next species feed from within a rolled cacao leaf, but none of those that I have seen had rolled a leaf.

Theope foliorum Bates. Larva very similar to the preceding, except that the body colour is more yellowish green and the 8th abdominal segment mainly black above; there are only about 60 prothoracic protuberances. Also always attended by ants. Neither species of *Theope* is at all common and they have only been seen during the dry season.

Family Lycænidæ. "Hairstreaks."

The larvæ of this family are short and broad, rather slug-like, with a small head concealed by the projecting prothorax, and with the sides of the body overlapping the very small legs and prolegs.

Thecla bitias (Cram.). Larva about 18 mm. in length, pale greyish green with a dark olive-green dorsal stripe, broad anteriorly and tapering towards apex of abdomen, diagonal lateral dark stripes on the 3rd to 6th abdominal segments. Mesothorax projecting forwards in a bilobed

process overhanging prothorax. Body covered with rather numerous very short brown and red hairs, which are slightly longer on the lateral margins and on the pro- and mesothorax. Pupa green, wing cases and apex of abdomen mottled with brown. Duration of larval stage about 12 days, pupa 8-10 days. The larva is not attended by ants in the field, but in the laboratory is eagerly sought out by *Tapinoma* sp. Fairly common throughout the year.

Thecla hemon (Cram.). Larva 18-20 mm. long, smooth, covered with a short fine pale pubescence, a few larger darker hairs mainly on the thorax and at the apex of the abdomen. Body colour varying from pale green to a deep mauve, according to the colour of the flush leaves on which it has fed. The early instars of the larva are pale yellow, with two longitudinal dorsal ridges, and tufts of rather long pale hairs on the ridges and on the lateral margins of the body. Pupa light brown speckled with darker brown, with tufts of a few short coarse hairs in two rows on the dorsum and at the sides. Larval period 11-12 days, pupa the same. Common throughout the year, though it has never been found abundant enough to do appreciable damage.

T. hemon is parasitised by an Ichneumonid of an undetermined genus of the tribe Campoplegini. The frequency of parasitism seems to be variable, for over fifty per cent. of larvæ collected in the Diego Martin and Santa Cruz districts were parasitised, but only about ten per cent. of those at I.C.T.A., yet the species is certainly not less common in the two former localities. A parasitised larva when almost full grown shrivels up and becomes "mummified" and the Ichneumonid emerges 6-8 days later.

A Chalcid, *Spilochalcis* (*Heptasmicra*) sp. near *lycaenae* Cam. has emerged in small numbers from pupæ of *T. hemon*. This may be a hyperparasite: it has a long life cycle, since from larvæ collected at least seven days before they pupated the adults did not emerge until 21-25 days after pupation of the hosts.

Thecla marsyas (L.). Length of larva about 25 mm., smooth, ground colour a rather bright green which is obscured by a short dense red pubescence, a few inconspicuous longer hairs at the sides and on the prothorax, and one pair on the mesothorax. Pupa dark brown, with tufts of short hairs on the anterior margin of the head, a single dorsal row on the thorax and a double row of smaller tufts on the abdomen. Larval stage about 13-14 days, pupa 9-12 days. Occasional throughout the year, more frequent in the dry season.

Parasitised by a Tachinid, *Actia* sp. Twenty-one larvæ of this parasite have emerged from a single full fed larva of *T. marsyas*. They pupated after a few hours and the adults emerged 12 days later.

**Thecla orsina* Hew. The larva of this species has not been distinguished from that of *T. marsyas*. Two specimens were bred from a number of larvæ, all thought to be *T. marsyas*, collected at Diego Martin. It is presumably very uncommon.

Thecla talyra Hew. Larva 11 mm. long, mainly apple green; the prothorax with a pair of dark spots on dorsum, meso- and metathorax with a pair of fainter subdorsal spots; first seven abdominal segments with the dorsum broadly dark, the first segment also with a lateral dark spot below the spiracle; on the 4th and 5th segments the dark area extends to the pleuræ below the spiracles;

terminal segments with a narrower dark dorsal stripe. Fairly thickly covered with short brown hairs, a few longer hairs on prothorax, sides of mesothorax and at apex of abdomen. Pupa brown mottled with black, with short brown hairs at both extremities and on the mid dorsal line of the thorax. Enclosed in a very slight cocoon of a few strands of silk, in a folded leaf. Larval period about 15 days, pupa 10 days. The larvæ are invariably attended by ants.

This species has only been found in a restricted area at Santa Cruz where the larvæ are not uncommon, but are heavily parasitised by a Chalcid, *Spilochalcis* (*Heptasmicra*) sp. (different from that reared from *T. hemon*). Most species of *Spilochalcis* are hyperparasites, but no other parasite has been bred from *T. talyra*.

**Thecla tympania* Hew. Larva about 16 mm. long, bright apple green, dorsal stripe darker green; paler green or yellowish at the sides and on the paired abdominal dorsal prominences. Pubescence fine, pale; there are also rather numerous longer stout brown hairs with darker tips. Pupa brown, mottled with dark brown, rather evenly covered with short coarse hairs except on the wing cases, those on the sides of the head and apex of abdomen somewhat longer. Larval period about 13-14 days, pupa 11-12 days. Generally not uncommon. Both this species and *T. bitias* are difficult to see, since they somewhat resemble the very young uncurled cacao leaves on which they are often found resting.

Family Geometridæ.

"Looper" caterpillars with abdominal legs only on the 6th and 10th segments.

**Aeschropteryx sectata* Guen. Larva 50-60 mm. long, head and prothorax about two-thirds the width of the abdominal segments, the mesothorax somewhat expanded laterally; a dorsal protuberance on 8th abdominal segment bearing a pair of small dark conical processes. Fawn-coloured, rather darker at the sides of the metathorax and first two abdominal segments. Some specimens have an interrupted whitish dorsal line which may be broader at the posterior ends of the segments. Pupates in a slight cocoon among leaves. Larval period about 21 days, pupa 12-13 days.

Paragonia spp. Larvæ of this genus have not been distinguished from each other nor, with certainty, from those of the preceding species, though they tend to have a broader and more definite whitish dorsal line. Three species have been bred from cacao, which have been tentatively identified by the British Museum as *P. tasima* Cram., **P. procidaria* H.-S., and an unnamed species. Both the adults and larvæ appear to be very variable.

These four large Geometrid larvæ are at times not uncommon in the Santa Cruz valley, but are difficult to find since they very closely resemble lichen-covered twigs.

Boarmia bipennaria Guen. Larva about 40 mm. long, uniformly olive green, with a small black spot just posterior to the spiracle on the 2nd abdominal segment. Larval period about 22 days, pupa 10 days. Occasional, only noticed from January to June, usually on chupons.

Microgonia vesulia (Cram.). Larva about 60 mm. in length, finely mottled with buff and grey. Mesothorax with a transverse dorsal hump; a pair of small brown ovoid protuberances on dorsum of 4th abdominal segment. Duration of larval stage probably about four weeks, of pupa 11 days. Occasional, only seen in the dry season.

**Nematocampa completa* Warr. Larva about 30 mm. long, dorsum of thorax and first two abdominal segments yellow with a narrow brown dorsal stripe, remainder of abdomen mainly mauve with an oval brown spot at posterior end of dorsum of 8th segment, and indistinct paler lateral diagonal stripes. Two pairs of elongate dorsal processes at the posterior end of the second and third abdominal segments; these are some 15 mm. in length; when the larva is moving they are extended laterally, but when at rest each pair is closely adpressed except at the ends, which diverge and are twisted like a corkscrew. Larval period unknown, pupa 8 days. I have only seen a single example of this remarkable larva, at Diego Martin in August, but there were several unnamed specimens of the adult in the Lamont collection.

**Physocleora pauper* Warr. Larva 25-30 mm. long, reddish brown, usually rather darker on dorsum of 2nd to 4th abdominal segments; a few pale flecks forming an incomplete dorsal stripe, and a small pale spot at the sides of the 2nd segment. November to May, occasional, usually on chupons.

Family Arctiidæ.

Epantheria muzina Oberth. Larva about 50 mm. in length, black, with three pairs of verrucæ on prothorax, four pairs on meso- and metathorax, and six pairs on each abdominal segment—three pairs above the spiracle and three below. The dorsal verrucæ are black, the subdorsal ones dark brown and the sub-spiracular ones reddish. In the earlier instars all the verrucæ are red. Each verruca bears numerous shortly pubescent hairs, about half as long as the diameter of the body, mainly black, but many of them reddish at the base. Pupa in a thin cocoon among leaves. Larval period about five weeks, pupa 16 days.

This species has only once been observed on cacao, at I.C.T.A. in November, 1952, when considerable numbers were defoliating small experimental cacao plants grown under artificial shade. It has also been seen on various weeds and cacao is probably not a normal host plant.

Parasitised by the Tachinid *Carcelia* (*Calocarcelia*) *flavivestris* (Wulp) var. As many as eight have been bred from one host, some pupating in the host, which dies as a pre-pupa, and some emerging and pupating on the ground.

Halisidota polyodonta Hampson. Larva about 30 mm. in length, dark slate-blue, each segment with three contiguous lateral yellow spots and a pair of dorsal spots each of which bears a tuft of numerous shortly plumose hairs which are bright yellow except the dorsal tufts on the 7th and 8th abdominal segments, which are brown. The prothorax also bears about 6 much longer white sub-plumose hairs, the mesothorax two pairs of tufts each of 6-8 similar hairs, and the 8th abdominal segment a pair of tufts of about 12 white hairs. The 9th segment has a pair of tufts of about 10 short black hairs which are densely plumose at the tip. Pupa in a tough oval pale yellow cocoon, on a leaf or twig. Larval stage about 23 days, pupa 12 days. Occasional, only in the dry season.

Melese laodamia (Druce). Larva 30-35 mm. long; head dark chestnut brown with a pale inverted Y-shaped mark; body very dark brown with rather indeterminate paler brown blotches in the centre of each segment. Each thoracic segment has four and each abdominal segment five pairs of black verrucæ, the dorsal pair smaller

than and anterior to the subdorsal pair, a larger verruca just above and a smaller one just behind the spiracle ; and a large one above the orange-coloured abdominal prolegs. Each verruca bears numerous shortly plumose hairs, about as long as the diameter of the body, which are brown at the base and black at the tip. In the penultimate larval instar the pale markings on the dorsum are more distinct and there is also a broken pale lateral stripe. The dorsal verrucæ on the prothorax, in addition to the usual hairs, bear a single black hair terminating in a conspicuous white plume. Many of the subplumose hairs on the lateral verrucæ are pale. Pupa in a thin cocoon in which are incorporated the larval hairs ; duration of larval stage about 25 days and of pupal stage 10-12 days. Fairly common throughout the year, mainly on chupons. According to Kaye and Lamont (1927) the larva also feeds on " Barbados cherry " (*Malpighia*).

The following parasites have been reared :—

Tachinidæ : *Carcelia* (*Calocarcelia*) *flavirostris* (Wulp) var. The host larva spins its cocoon but dies before pupating, up to 3 parasites emerging from one prepupa 11 days later. Ichneumonidæ : tribe Lissonotini, gen. and sp. unknown. This also emerges from the prepupa. *Enicospilus* sp. This Ichneumonid pupates within the dead body of the nearly full-grown larva. Braconidæ : *Microgaster* sp. Kills the host larva before it is fully grown.

Melese flavipuncta Roths. Larva very similar to that of *M. laodamia*, but the pale lateral stripe persists in the last instar, the thoracic verrucæ are reddish and the sub-plumose hairs arising from them are rather paler on their basal half. Occasional throughout the year ; less common than *M. laodamia*.

Pelochyta arontes (Stoll.). Length of larva about 30 mm. Head and prothorax yellow with numerous black spots ; body mostly black except the yellow posterior margin of the mesothorax, the pink anterior margin of the metathorax, an elongate red dorsal spot on each of the 2nd to 7th abdominal segments, the 7th segment also with a pair of yellow spots near the hind margin of the dorsum and the 8th with a smaller pair near the anterior margin, and a cream-coloured lateral stripe on all abdominal segments. The mesothorax with three pairs of tufts of long, forwardly directed, slightly plumose hairs, the lateral tufts white, sub-dorsal partly white and partly dark, the dorsal pair dark and containing two or three longer hairs which are more plumose at their apices. Metathorax with four pairs of tufts of white sub-plumose hairs. First and second abdominal segments with a thick ruff of black sub-plumose hairs and a lateral tuft of shorter white hairs. Third to sixth segments with four pairs of tufts of white hairs and two pairs of dense tufts of shorter black hairs on the dorsum surrounding the red spot. Seventh segment similar, but the longer tufts mainly of dark hairs. Eighth segment with two contiguous tufts of long dark hairs on the dorsum each with one longer hair which is more plumose at the apex, and three lateral tufts of numerous white hairs the upper one containing also a few much longer white hairs. Ninth segment with two pairs of tufts, the dorsal pair of dark hairs, the lateral ones mainly white. Tenth segment with similar dark hairs not arranged in definite tufts. Pupa in an oval cocoon formed of silk and the hairs of the larva. Larval stages about 22 days, pupa 11 days. Occasional throughout the year. Also recorded on Angelin (*Andira inermis*).

Family Noctuidæ. Sub-family Acronyctinæ.

Calymniodes mastoides Hampson. Larva about 30 mm. long ; very dark brown, speckled with white at the sides, a narrow white dorsal stripe on the abdominal segments bordered by a light brown area on 3rd to 8th segments which is triangular on the 3rd, widest on the 4th, and gradually decreasing in width to the 8th ; a lateral cream coloured spot on 4th and 8th segments and a pair of sub-dorsal light brown spots on the 9th. Only observed in the Santa Cruz valley during March. Three or four larvæ are usually found together.

Laphygma eridania (Cram.). Larva about 30 mm. in length, olive green with pinkish dorsal and sub-dorsal stripes and a paler lateral stripe, orange round spiracles ; a pair of triangular black marks on the dorsum of 1st and 8th abdominal segments. Larvæ have very occasionally been found on cacao, the normal host plants are Solanaceæ.

Laphygma frugiperda Smith and Abbott. (The Corn Leaf-worm). Larva about 30 mm. long, rather variable in colour, grey to yellowish green, with a narrow inconspicuous paler dorsal stripe and a pair of more definite yellow sub-dorsal stripes, just below which there is a small elongate jet black spot near the anterior margin of the 2nd to 8th abdominal segments ; a broad brownish yellow lateral stripe ; area round the spiracles sometimes tinged with purple, especially on 1st, 7th and 8th segments. Each abdominal segment with a pair of small black spots bearing a short stiff black hair on the dorsum near the anterior margin, a similar pair near the middle of the segment just inside the sub-dorsal stripe, and another pair just above the spiracles. Larval period about three weeks, pupa 10 days. This species has only once been seen on cacao in the field, but at I.C.T.A. it commonly attacks young cacao in greenhouses or in the laboratory and, if not spotted in the early stages of an attack, can do considerable damage. The larvæ tend to be cannibals, even when abundant food is available. *L. frugiperda* is a common pest of maize and is occasional on numerous other host plants.

Prodenia spp. (probably *androgea* (Cram.), *dolichos* (Fabr.) and *latifascia* Walk.). Specimens of *Prodenia* from larvæ feeding on cacao have been tentatively identified by the British Museum as belonging to the above three species. I have, however, not been able to correlate the considerable variations in the larvæ with the adults, which are also variable, and it is possible that only one highly variable species is concerned. The larvæ are about 60 mm. in length, brown, greenish-brown or purplish, minutely speckled with yellow, with usually rather ill-defined light brown, yellow or mauve lateral and sub-lateral stripes and a narrower dorsal stripe. Some of the segments have a pair of inwardly pointing jet black triangles, their bases resting on the sub-dorsal stripe ; the following variations in position have been observed :—

On the 1st and 8th abdominal segments.

On the 8th and a smaller one on the 7th.

On the mesothorax and 7th and 8th.

On the 4th to 8th, increasing in size.

On the meso- and metathorax, and 3rd to 8th increasing in size.

On the meso- and metathorax and 1st to 8th, all equal in size.

On the prothorax and 1st to 8th, increasing in size.

Larval period about three weeks, pupa two weeks. Fairly common throughout the year, especially in the dry season: they feed mainly on chupons. The larvæ are very general feeders and can be found on a wide range of host plants, among those of economic importance may be mentioned banana, cotton, all Solanaceous crops and sweet potato.

Sub-family Erastriniæ.

Angitia albicauda Hampson. The larva, a "semi-looper" with functional abdominal legs only on the 5th, 6th and 10th segments, is about 30 mm. in length, bright green with cream and pink markings at the sides of the thorax and on the dorsum of the 1st and 7th abdominal segments. The penultimate instar is green with five darker dorsal patches and an interrupted cream and pink lateral stripe. The early instars are brown with a pale lateral stripe. Larval period about three weeks, pupa four weeks. Not uncommon, December to July.

Sub-family Hadeniniæ.

Catephiodes zuelana (Sch.). Larva about 30 mm. long, a "semi-looper," the prolegs on the 3rd and 4th segments rudimentary; ground colour usually yellow, sometimes tinged with green or blue, variably marked with black and paler spots; conspicuous bright orange bands on dorsum of first three abdominal segments. Larval and pupal stages both about three weeks. Always present and occasionally common enough to cause considerable defoliation.

An Ichneumonid, of an unknown genus belonging to the tribe Lissonotini, has been reared from this species: the adult parasite emerges from the pupa of the host. A large black Attid spider has been observed to prey on the larvæ.

Sub-family Noctuiniæ.

Hemeroblemma rengus (Poey). Larva about 65 mm. long, reddish brown, finely reticulated with yellowish green, indistinct paler oval marks on the dorsal line; 8th abdominal segment with a pair of small conical protuberances, yellow at the apex and bearing a long dark hair; 9th segment with two pairs of long hairs; a minute yellow dorsal spot on the anterior margin of 2nd abdominal segment and on the outer sides of the protuberances. Abdominal feet only on the 4th, 5th, 6th and 10th segments. The early instars are black with sparse long hairs and without prolegs on the 4th segment. Duration of larval stages about 17 days, of pupa 12-14 days. Generally distributed and not uncommon throughout the year.

Melanchroia leontia (Stoll). Larva about 50 mm. long, very similar to that of *H. rengus*; the pale reticulations rather brighter yellow, and no yellow spot at the base of the tubercles on the 8th abdominal segment. Duration of the larval stage considerably longer than that of *H. rengus*, about 28 days; the pupal stage lasts 11-14 days. Throughout the year, not uncommon.

Pod Borers

Family Olethreutidæ.

(?) *Ecolytolopha puntidiscans* Hein. (This has previously been recorded as *Gymnandrosoma* sp. (Lamont and Callan, 1950).) Larva about 13 mm. long, head and prothorax shining brown, rest of body dirty yellow with two pairs of darker spots on dorsum of each segment.

The larvæ tunnel in the pod wall, very often in pods attacked by Black Pod disease (*Phytophthora palmivora*) though they can attack perfectly sound pods if quite ripe. There may be some discoloration of the pulp of a bean lying close to a boring, but no injury is done to the beans themselves. Twenty or more larvæ may occur in one pod. The larva maintains a hole to the exterior, from which a quantity of frass exudes; it pupates in a cocoon of frass in the tunnel and on emergence of the adult the empty pupal case is left partly extruded from the hole. The life cycle from hatching of the egg to emergence of the adult is rather over one month. Locally common, especially perhaps in neglected cacao.

Family Erycinidæ.

Nymphidium calyce Feld. Several larvæ of this species, which is normally a leaf-feeder (p. 69), have on one occasion been found tunnelling in an unripe pod. No damage was done to the beans.

Family Aegeriidæ.

A species of an unknown genus has once been found boring in an unripe pod at Diego Martin. This appears to be distinct from *Aegeria theobromae* (Busck) recorded from dry pods by P. L. Guppy (Busck, 1910) which I have not met with myself.

Pod Miner

Family Gracilariidæ.

Marmara sp. The whitish much flattened larva of this species causes the conspicuous serpentine mines to be seen just under the epidermis of the majority of cacao pods in Trinidad. No damage is done to the cacao.

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Studies on Cacao Beetle (*Steirastoma breve* Sulz. Lamiidae)

By
R. G. Fennah

I. LARVAL INCIDENCE IN RELATION TO MANURIAL TREATMENT AND LIGHT INTENSITY

GUPPY (1911: 17) notes that in cacao fields the favourite haunts of adult cacao beetles are exposed sunny areas, and quotes Anstead for the observation that the beetles "dislike" dark places where the sunlight cannot reach. It is not explicitly stated whether oviposition occurs most plentifully in the open spots favoured by adults for feeding and mating, though the inference that it does so may permissibly be drawn from the context. Even if this is accepted as a general answer, however, it provides no information on the degree of association between such open spots and the oviposition site, "site" in this instance referring to the position of the chosen trees in the field, not to the chosen spots on the tree where the insect oviposits.

It has recently proved possible to clarify this point by examination of the incidence of larval damage on a compactly planted area of cacao trees growing under various light intensities.

Methods

The investigation was made on the trees of the Cacao Shade Experiment at the Imperial College of Tropical Agriculture. The layout has been described (Evans and Murray, 1953) and includes 960 trees comprising three ICS clones, 1, 60 and 95, which receive one of seven combinations of nitrogenous, phosphatic and potassic fertilisers or no treatment, and grow in one of five levels of light intensity, varying from 15% to 100%. Each light-treatment plot is split, with each half containing the full range of fertiliser treatments, but for reasons given

(Evans and Murray, 1953: 69) no advantage was taken of this part of the design in the earlier part of the life of the experiment. In 1953, however, the bamboo lath shade was removed from half of each shaded plot, leaving two blocks of 24 trees each receiving the original overhead shade at each light level below 100% (15% light, 48 trees; 25% light, 48 trees; 50% light, 48 trees; 75% light, 48 trees). The dimensions of each half plot are about 10×22 yards.

These trees were inspected individually by the writer and the number and position of larval tunnels was recorded under one of four categories (1) on otherwise undamaged bark, remote from the vicinity of forks; (2) at, or very near, forks; (3) at site of evident scrapes or bruises on the bark; and (4) in, or near, the stumps of amputated branches. It is to be noted that at this stage (2½ years) the trees were of relatively uniform size, and the diameter of the major limbs of the scaffold were as follows: main trunk (very short) 7.6-8.9 cm.; main branches (near base) 5.1 cm.; higher up 3.8 cm.; larger secondary branches 2.5-3.2 cm. Pruned "amputated" branches generally left stumps of 1.9 cm.-2.5 cm. in diameter. A larval tunnel is observable at a late stage as a channel or a weal in the bark, and at an early stage as a small "efflorescence" of moist reddish brown woody debris (excreta). Investigation with a knife point shows the tunnel below.

Results

In a simple comparison of trees with larval damage at different light intensities the results are as follows:—

TABLE I

Number of trees showing larval damage by <i>Steirastoma</i>								
Plot	Block I		Block II		Blocks I and II		Total no. of trees	
	shaded	unshaded	shaded	unshaded	shaded	unshaded	shaded	unshaded
15%	5	15	4	15	9	30	48	48
25%	3	3	4	11	7	14	48	48
50%	3	14	8	15	11	29	48	48
75%	4	3	7	8	11	11	48	48
100%	—	8	—	13	—	21	—	96
	15	43	23	62	38	105	192	288

Percentage of trees with larval damage.

15% light-18.76%
25% light-14.58%
50% light-22.90%
75% light-22.90%
100% light-36.45%

Mean -23.12%

The regression of the number of trees infested on light intensity $b = +.2114$ is significant at the 1% level. The regression graph is given in Fig. 1.

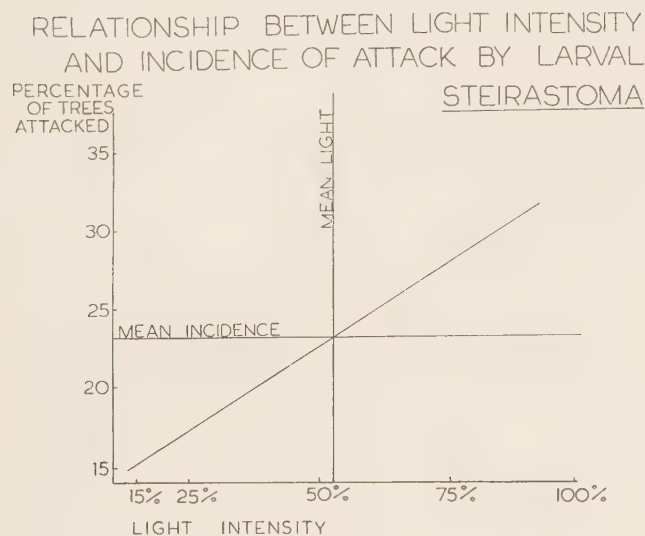


FIGURE 1

Regression graph showing the relation between light intensity and the percentage of trees damaged by cacao beetle larvæ.

If the corresponding half-plots of Block I and Block II are compared, it is seen that the mean difference is 2.70, the higher infestation occurring in Block II. This difference is significant ($t = 2.891$ $n = 9$) at the 2% point.

The distribution of attacked trees between the three clones used in the experiment was as follows: ICS 1, 39 trees; ICS 60, 54 trees; ICS 95, 50 trees. The differences between the various manurial treatments is as follows: N-14; NP-17; NK-23; NPK-18; K-12; PK-23; P-16; control-20. The respective differences between the N and minus N treatments, P and minus P, and K and minus K treatments are not significant.

The distribution of larval tunnels between the four position categories enumerated above is as follows.

TABLE II

Position	No. of tunnels		No. of trees attacked*	
	Block I	Block II	Block I	Block II
Exposed bark (1)	12	40	9	32
"Forks" (2) ...	5	14	5	11
Bruised bark (3)	26	13	15	13
Base of cut branches (4)	50	68	30	54

* Some trees, attacked at more than one point, are entered more than once.

The difference between intensity of attack on previously damaged and previous undamaged bark tissue (1)+(3) and (2)+(4) (1.32 and 1.37 tunnels per tree) is not statistically significant; the difference between intensity

of attack on level bark surface (1)+(2)* and on creviced or cut surfaces (3)*+(4) (1.07 and 1.40 tunnels per tree respectively) is statistically significant; ($P = 0.01$). The small number of tunnels in categories (2) and (3) does not permit any conclusion to be drawn concerning the relative attractiveness of damaged or creviced tissue (that is, between olfactory and surface texture attractiveness).

Discussion

The results show that oviposition followed by successful larval establishment is much higher on exposed than on shaded cacao and the simplest explanation of this is that more eggs are laid on exposed trees. The size of the half plots which formed the randomised units is so small that even the shortest flight—or even a walk along two contiguous branches—could lead the adult female out of the exposed and into an unexposed area, and vice versa. As Guppy and others have observed the adults feed in preference on exposed trees, of which the thin bark of the outermost shoots forms their sole food, and the fact that the highest larval infestation occurs on the trees which are most attractive to the adults is consistent with the view that the beetles lay most frequently on such trees. An alternative possibility, namely, that beetles lay more or less at random, but that egg and early larval mortality is substantially higher in the shaded plots, and becomes accentuated with increasing shade, appears improbable as a complete explanation of the observed distribution of larvæ in view of the small size of the plots used and the success of more than a third of the larvæ in a shaded environment. Although the likelihood of random oviposition on cacao is less than that of selective oviposition, the possibility that shaded trees are associated with conditions less favourable to hatching and larval development cannot be disregarded.

The fact that cacao beetle can, and does, maintain a higher population in unshaded cacao raises the question of the mechanism involved. It is seen that the fertilisers, as applied, did not affect the relative abundance of larvæ. The incidence of attack on trees that were superior in size, leaf area and yield and on those that were distinctly inferior was not significantly different, but the point cannot be regarded as settled as relatively few of the attacked trees fell into the usefully contrasted extremes of these categories. Of the three clones used, none was more attractive than the others: the total number of trees attacked was lowest in the case of ICS 1, and it is possible that under heavier attack this difference might be more marked. The individual records of tunnels per tree did not show at this stage any "favourite trees" which were the target for repeated attack.

The simplest conclusion is that the "build up" of population is dependent on factors directly associated with increased insolation. Of these, as contrasted with shade conditions, the most evident are (1) increased water stress during period between 10.0 a.m. and 5.0 p.m.; (2) increased carbohydrate content; and (3) increased metabolic rate,† possibly general, but certainly as far as ageing of leaf tissue is concerned. It was with the object of

* It is broadly assumed that this total refers only to "level bark"; one or two bruises, however, occurred on the outer side of the branch near a fork; "fork" tissue of the size quoted begins to show marked crevice formation through overgrowth.

† The evidence is available, but not presented here.

throwing light on the potentialities of the beetle for exploiting the forms of carbohydrate present that the investigation described in the second part of this study was undertaken. It was noted that the trees in Block II were more heavily attacked than those in Block I. Yields in the former block are higher, but no explanation of the difference in beetle incidence can yet be offered.

Guppy has recorded the occurrence of "favourite trees," which are repeatedly attacked. The present writer has seen old trees on which attack was abundant and quite clearly had been sustained over a long period. McKee (1944: 17) has recorded that attack occurred to a significantly greater extent on clones ICS 4 and ICS 5 than on ICS 8 under presumably equal growth conditions at River Estate. The relatively high susceptibility of ICS 5 has been confirmed by the observations of other workers. The clonal aspect of selection, on a good soil type, can only be attributed to genetic factors, and in view of such genetic variation, in a seedling population it is inevitable that individual trees of intrinsic high attractiveness should occur. But, to judge from experience to date with clonal cacao, they form only a very small percentage of the total.

The question of zonation of attack, that is, the places on the tree where attack occurs, is apparently complex. Adult scarification of the thin bark on the most exposed branches may well represent the exploitation of a relatively narrow tissue-zone—the area where the juvenile tomentum of glandular hairs is absent, but where the chlorophyllous subepidermal layer is still present. The choice of cacao, other Sterculiaceæ and some Malvaceæ as hosts suggests an inherent olfactory conditioning: a preference probably exists for a certain kind of aroma; but as yet there is no clear evidence whether this kind of aroma is more attractive when strong than when weak.

The data show that creviced wood, whether in the region of cut branches or not, is favourable to effective oviposition. The callused bark which develops at the sides of old larval-tunnels, or channels, clearly forms a further type of creviced tissue. Carr (1894) states that beetles return preferentially to damaged trees, and adds: "This I suppose is due to the sweet gum which flows from recent wounds and which, as is well known, possesses some peculiar attraction to the beetle." The writer has so far not been able to substantiate this connection: there would certainly seem to be a limit to the period during which the "gum" is attractive, as the writer has seen no signs of adult beetles near, or feeding marks on, any of the numerous exudations of tasteless mucilage he has examined. In the case of an alternative host, "Chataigne maron" (*Pachira insignis*), Guppy (1911: 23) records that adults are attracted to freshly cut wood, while Carr and Anstead note the readiness with which beetles find wounds made in cacao trees. Three possible chemical attractants are present at these sites: (1) the "sterculaceous" odour, released in greater amount from *freshly* cut tissue; (2) the "available food" odour presumably emitted by the freshly exuding protoplasmic sol; (3) the "rotting tissue" odour emitted by the frass and breaking down tissues in the tunnel walls. On balance, the first seems to be the most likely agent.

The discovery of forks and grooves is a matter of visual and tactile exploration, but there is one factor of substantial importance to be taken into account. A fully fed cacao beetle larva, even if puny, has a girth of 6 or 7 mm.,

so that the habitat in which it feeds must be capable of accommodating an insect of this size. This means that the smaller branches of the tree are unsuitable for effective colonisation, and in fact they appear to be avoided by the ovipositing female. None the less, as with other branches, they have forks, but the female beetles do not appear to be led into wasteful egg-laying. At the other extreme, there is, on an old tree, an almost massively thick cortical layer available for exploitation, and the writer's observations on a "favourite tree" in Grenada left no doubt that larval development is entirely possible in such tissue. Yet the bark tissue of the main trunk of a fully mature tree is virtually free from beetle larvæ, unless it has been repeatedly attacked from the time when the tree was young. In the absence of any obvious physiological deterrent, it may perhaps be assumed that attractants are normally lacking or relatively weak.

Summary

(1) The number of trees bearing larval tunnels of cacao beetle, in three cacao clones grown under varying light intensities, has shown a highly significant increase with increasing light intensity.

(2) Under the prevailing degree of larval infestation no significant differences were established between the clones used, or between the manurial treatments given.

(3) The number of larval tunnels was significantly higher in creviced or cut bark than in smooth level bark.

(4) As adult cacao beetles are known to prefer exposed trees to shaded, it is provisionally assumed that the higher prevalence of larval tunnels in unshaded cacao is due to preferential oviposition on unshaded trees and possibly enhanced larval survival. Increase of population is most rapid in conditions directly associated with increased insolation of the trees.

II. CARBOHYDRATE DIGESTION IN THE CACAO BEETLE.

In the foregoing part of these studies it has been shown that the largest beetle populations are built up under full sunlight. It is known that the adults and larvæ feed only on cortical tissues, and that the latter, notwithstanding the apparent uniformity of the host substrate, has a developmental stage of appreciably varying duration (Guppy 1911: 6). It was considered advisable to examine the physiological capabilities of the insect for exploiting the tissues among which it lives, at least as far as the digestion of carbohydrate is concerned.

The digestive tract of the adult presents no obviously abnormal features. The oesophagus opens into a wide crop which is followed by a proventriculus with its inner walls thrown into six stout ridges, each of which is densely beset anteriorly on its inner walls with a brush of orange-brown setæ directed backward, and this in turn is followed by a long simple midgut and by a hind-gut which is superficially similar to the midgut. The alimentary canal of the larva comprises an oesophagus, crop, midgut and hindgut: no proventriculus is structurally differentiated. Salivary glands appear to be wholly absent.

The food of the adult consists of the chlorophyllous layer and the thin papery overlying bark of the younger branches, with the exception of the youngest unhardened tissue. The food is ingested in the form of small more or

less rhomboidal blocks: these to a very great extent retain their shape on passage through the gut. The cell contents, at least as far as the outer cells are concerned, are dissolved out, but grains of starch have been observed (after teasing the tissues apart and staining with iodine solution) in particles which had reached the hind end of the gut both in adults and larvæ. The larva feeds in the cortical tissues, which are taken in as torn shreds of vascular tissue interspersed with lenses of parenchyma. Sometimes cambial and woody tissues are ingested where the larva is boring in a thin-barked branch.

The Hydrogen Ion Concentration of the Alimentary Canal

The methods used were those of Wigglesworth (1927) both for measuring the pH of the alimentary canal and for estimating enzyme activity. Phenol red, bromothymol blue, bromocresol purple, methyl red and bromophenol blue were used as indicators. Colour comparisons with buffers were made on a white tile and also in sealed capillary tubes compared under a low power of a binocular microscope. The pH of the gut both when empty and when partly filled with food was measured, the fluid being withdrawn by means of a fine pipette. A modification of the "white-tile" technique which was found to be useful when examining the empty gut consisted of placing a half-circle of small drops of different buffer solutions on a glass stage within the field of a low power binocular microscope, and adding with a fine pipette the same quantity of indicator to each. A short length of the alimentary canal was laid gently into a drop of the same indicator and one end was pressed gently with a glass point. The fluid inside was partly expelled from the opposite end into the indicator and its effect on the indicator was observed at the moment of contact, when its concentration is maximal.

The results were as follows:—

Crop (adult), range of pH 5.6-6.0; average of 15 estimations 5.5.

Midgut (adult), range of pH 5.7-6.2; average of 15 estimates 6.0.

Crop (larva), range of pH 5.9-6.6; average of 15 estimates 6.1.

Midgut (larva), range of pH 5.9-6.8; average of 13 estimates 6.4.

An emulsion of the crop of the larva was incubated with glucose, lactose and maltose. In the following table the entries in the first column (1) under each head refer to an emulsion in distilled water of the crops of larval *Steirastoma* incubated with 5 ml. of a 2% solution of the sugar and 5 drops of methyl red, under sterile conditions, while the entries in the second column (2) refer to controls in which the emulsion had been held at 100°C. for several minutes. Y indicates a reaction yellow to methyl red, O means light orange, while the figures give the approximate pH.

TABLE III

Time	2% glucose		2% lactose		2% maltose	
	1	2	1	2	1	2
3.0 p.m. ...	Y	Y	Y	Y	Y	Y
6.0 p.m. ...	O	Y	O	Y	O	Y
9.0 p.m. ...	5.5	Y	5.5	Y	5.5	Y

The crop fluid gave a yellow colour with dilute ferric chloride, while no reaction was observed with Gunzberg's test for hydrochloric acid and Brigg's test for phosphates. Bacteria were found in smears of the crop contents. It was not possible to give experimental diets to the insects, but the general picture fits so closely to that found by Wigglesworth with regard to the cockroach that it appears safe to assume that the acidity in the crop is largely due to organic acids produced by the activity of micro-organisms. The range of hydrogen ion concentration in both the adult and larval intestine is in close agreement with that found in the cockroach.

The Digestion of Carbohydrates

As mentioned above the adult cacao beetle feeds on the epidermis and chlorophyllous layer of the young bark, while the larva feeds in the cortical tissues of the wood. Where the bark is thin, the larva as it grows in size frequently removes cambial and woody tissue. The gross difference in the food of the two stages is that the food of the adult comprises epidermal cells, chlorophyllous cells, but no vascular or woody tissue, and normally no mucilage, while that of the larva includes no epidermal or chlorophyllous cells, and substantial amounts of vascular tissue, together with parenchyma, which regularly occurs in large "lenses" between the sinuate vascular strands: mucilage cells are normally and frequently encountered.

A microscopic examination of the food of the adult at different stages of its passage through the gut showed, in the case of the adult, that the individual "mouthfuls" of tissue with which the crop is engorged are passed singly into the midgut. The presence of the six-ridged "gastric mill" might suggest that some process of trituration or crushing takes place, but the brush-like structure of the sclerotised elements appears better adapted to forcing the food backward, and it is evident from inspection that the mouthfuls of food for the most part do not show any obvious change in size throughout their passage. The outer cells are torn and their contents entirely removed: the inner cells remain intact, though their contents may show some degree of disorganisation and discoloration: many cells further inside appear to escape attack, and even the colour of the chlorophyll remains. In the larva the lignified tissues are not broken down, and even the delicate cellulose walls of the large mucilage cells are not digested, even when fully exposed to the digestive fluid.

Methods

The preparations of active enzymes were made up separately for larvæ and adults, as glycerol extracts, dry preparations, and on occasion as fresh extracts ground with the smallest amount of water and 5% thymol in alcohol.

The fresh and glycerol extracts were used in qualitative tests on a range of carbohydrate substrates. Reducing sugars were estimated by the method of Hagedorn and Jensen. The sign + in the following table (Table IV) indicates that the amount of reducing sugar present was appreciably in excess of that found in the control in which "boiled" emulsion was used. The digestions were carried out in 5 mm. × 100 mm. tubes, each containing 0.5 ml. of substrate, with 0.2 ml. phthalate buffer + 0.1 ml. 1% NaCl and 0.1 ml. of enzyme extract. The pH of the buffer was about 6.0.

TABLE IV

	Adult	Larva
Starch (paste)	+	+
Sucrose	+	+
Maltose		+
Trehalose		+
Lactose		+(weak)
Melibiose		—
Cellobiose		+
Raffinose		+
Melezitose		+
α -methylglucoside		+(rather weak)
Aesculin		+
Inulin		+(weak)
Dextrin	+	+
Salicin		+
Cellulose { (cotton lint) (filter paper) }	—	—
Cellulose (modified)	—	—
β -methylglucoside		+
Cacao mucilage		+(very weak)

These results can be explained by assuming that the following enzymes were present in the extracts. β -fructosidase (sucrase), α -glucosidase, β -glucosidase, β -galactosidase (weak), amylase, and possibly inulase in the larva, and β -fructosidase and an amylase in the adult. α -galactosidase is apparently absent, as are also cellulase, cytase, and enzymes capable of attacking lignified tissue.

The method of preparing the extracts does not, of course, permit the conclusion to be drawn with certainty that these enzymes are normally present in the intestinal fluid. An exception to this is β -fructosidase which has been detected in the fluid expelled from the mouth of the living larva.

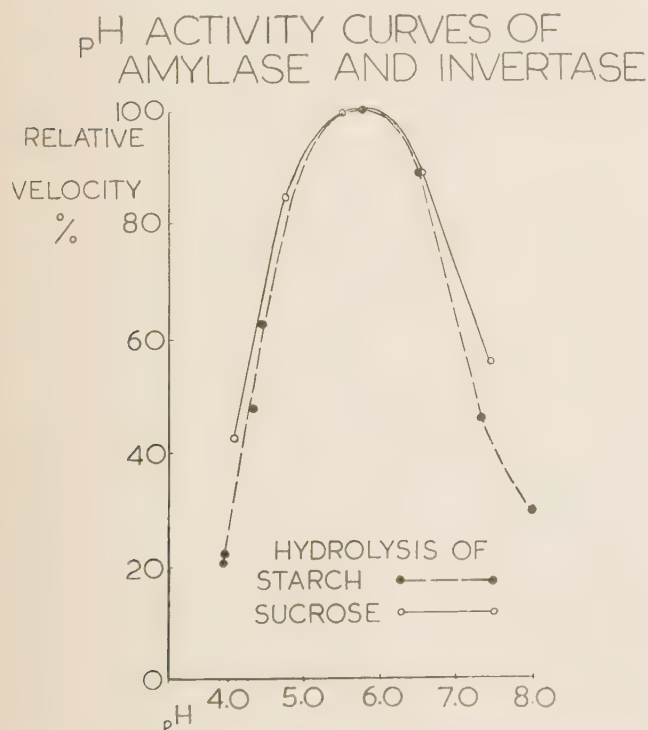


FIGURE 2

pH activity curves of (amyloclastic) amylase and invertase from adult *Steirastoma breve*.

The question whether an active amylase is present in the digestive fluid as well as in the tissues of the gut wall is of no practical consequence, as the starch reserve of the parts of the host normally used as food is infinitesimal.

The relative activity of α -glucosidase with melezitose and trehalose as substrates, and of β -fructosidase with sucrose as substrate was followed in the larva, and α -glucosidase with a maltose substrate, β -fructosidase (sucrose) and "amylase" (starch paste) in the adult. The relative rates of the hydrolysis of sucrose and of starch by the enzymes of the adult mid-gut are shown in Fig. 2, and those obtained for the remainder are closely similar with a maximum activity between pH 5.2 and 6.4. In a single experiment the relative activity of emulsin was followed with aesculin as the substrate: in this case maximal activity appeared to be reached at pH 6.8-7.5. It is sufficiently evident that the carbohydrate splitting enzymes are able to operate close to their maximal activity at the reactions normally found in the gut.

Wigglesworth (1927:806) has shown that the midgut invertase of *Blattella germanica* is readily inhibited by traces of silver nitrate, the relative activity being halved in the presence of .0001 N AgNO_3 . A very substantial reduction in activity also occurs in the presence of 1% NaCl. It was, accordingly, considered of interest to determine the concentrations of elements normally found in the plant at which the activity of the enzymes of the cacao beetle would be retarded. The test mixtures comprised: substrate 0.4 ml., buffer (5.8 or 6.0) 0.3 ml., sodium chloride 0.1 ml., enzyme preparation 0.1 ml., and the test compound 0.1 ml. The concentration of the last was adjusted so that it was present in the digesting mixture at the appropriate concentration. The relative activity is expressed as a percentage of the fastest time. Digestion in all cases was carried out at 25°C.

Results

The effect of different concentrations of ferrous sulphate and copper sulphate on the activity of amylase of larval *Steirastoma* is shown in Fig. 3. A phthalate buffer of pH 5.9 was used.

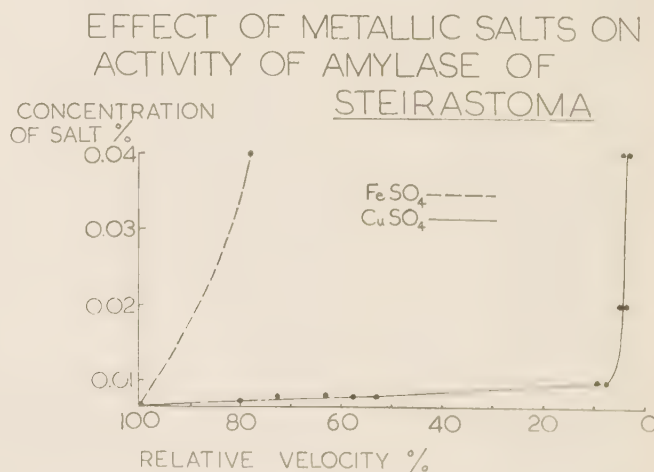


FIGURE 3

The effect of ferrous sulphate and of copper sulphate on the activity of (amyloclastic) amylase from larval *Steirastoma*.

The effect of various other salts is shown in Table V.

TABLE V

Steirastoma larval amylase incubated at 25°C. ; buffered at pH 5.8.

Relative activity	Percentage concentration of salt in digestion mixture			
	100%	75%	50%	10%
Silver nitrate ...	0.0003	—	0.003	—
Copper sulphate ...	0.0004	0.0035	0.004	0.010
Ferrous sulphate ...	0.004	0.04	0.35	—
Zinc sulphate ...	0.04	0.13	0.30	—
Manganese sulphate ...	0.04	0.14	0.60	—
Nickel sulphate ...	1.0	1.7	2.1	3.0
Sodium sulphate ...	0.02-5.00	—	—	—
Potassium sulphate ...	0.05-5.00	—	—	—
Boric acid ...	0.001-2.00	—	—	—
Urea ...	0.01-0.10	0.60	—	—
Calcium chloride ...	0.001-0.10	0.60	—	—
Sodium dihydrogen phosphate ...	0.01-0.7	—	—	—
Sodium molybdate ...	0.02-3.0	—	—	—

An arbitrary mixture of salts was made up in water in the following proportions. Ferrous sulphate 1.6%, manganese sulphate 3.05%, zinc sulphate 0.52% and copper sulphate 0.05%, and two further solutions were prepared by diluting this to half and a quarter of standard strength. Equal quantities of these solutions were incorporated in a digestion mixture made up as follows. Starch paste, 20 parts ; salt mixture, 1 part ; phthalate buffer pH 5.8, 3 parts ; enzyme preparation, 3 parts. The effect of concentration is shown in Fig. 4.

EFFECT OF COMBINED METALLIC SALTS ON ACTIVITY OF AMYLASE

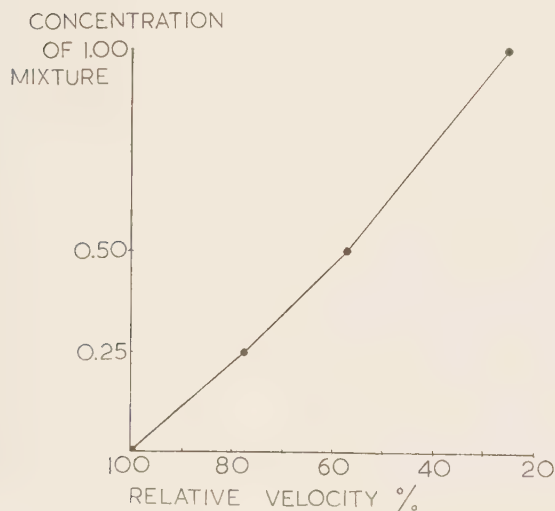


FIGURE 4

The effect of a mixture of ferrous sulphate, manganese sulphate, zinc sulphate and copper sulphate on the activity of (amyloclastic) amylase from larval *Steirastoma*.

In the control the salt mixture was replaced with equal amount of glass distilled water. Although only one enzyme, an amylase, was tested, the behaviour of this conforms well enough with the general behaviour of the other carbohydrate-splitting enzymes to give grounds for assuming that the curve obtained is of fairly general application.

It is clear that a concentration of one quarter the standard strength of salt mixture has depressed the rate of enzyme activity by some 25%. This is of interest as the concentrations of Fe, Mn, Zn and Cu at this dilution are roughly equal to the highest level of these elements which might be tolerated by the cacao tree. It would seem not unreasonable to expect the normal functioning of the carbohydrases of the plant to be adversely affected by the presence of salts of a higher concentration than this. It is at any rate clear that the margin between toxicity to the beetle and toxicity to the plant is relatively narrow, and it would, accordingly, seem unlikely that this mechanism plays any part in determining relative attractiveness of host trees. This, of course, in no way affects the possibility that the concentration of metallic ions may affect the insect through an entirely different channel.

Discussion

The mechanism of carbohydrate metabolism in the cacao beetle appears similar to that in the cockroach, as far as tests on both have been made. The enzymes present appear able to function efficiently within the range of pH reaction normally found in the gut. It is of interest, in view of the feeding habits of the insect, that its digestive mechanism should not be capable of breaking down insoluble carbohydrate. This limitation means that the carbohydrate food must come from the bark. Where the bark is thin, the nutritious layer is very narrow, and the larva, to accommodate its increasing bulk, removes woody tissues which are of no nutritional value. It is to be expected that this retards its development, and it is clearly to the advantage of the insect to live entirely in the nutritious substrate.

The picture of carbohydrate metabolism in the cacao tree is by no means complete, but the data which have so far been obtained have not revealed the existence of any substantial carbohydrate reserves in soluble form. It is possible that the mucilage is such a reserve, but it does not appear to be digested readily by the larva, if, indeed, it is utilised at all, while it is not even available to adult *Steirastoma* which feed on tissues in which it does not occur. If, as seems inevitable, it is assumed that the level of soluble carbohydrate in the trunk and branches of the cacao tree is not high, the development of maximal concentrations is only likely to occur under conditions which permit maximal photosynthesis. These conditions involve a high degree of exposure to sunlight, and there are grounds for considering that the general level of metabolic activity is higher in such conditions. In view of these facts, it is reasonable to explain the prevalence of the cacao beetle in unshaded cacao by assuming it to be a direct consequence of the greater availability of soluble carbohydrate, which provides a more nutritious pabulum for the larva, and possibly a greater gustatory stimulus to the adult.

Summary

(1) The hydrogen ion concentration of the fore part of the alimentary canal of both adult and larval cacao beetle

varies between 5.5 and 6.8. The acidity of the crop appears due, at least in part, to the activity of micro-organisms.

(2) The varying ability of extracts from the alimentary canal of adults and larvæ to attack various substrates can be explained by assuming the presence in the larval gut of β -fructosidase, α -glucosidase, β -glucosidase, α -galactosidase, and amylase, and in the adult gut of β -fructosidase and amylase. There is no positive evidence that the amylase is active in the digestive fluid. α -galactosidase, cellulase and cytase are absent and no mechanism has been detected for the breaking down of lignified tissue.

(3) Tests of the pH activity of amylase and sucrase showed that these enzymes are able to function optimally

at the pH normally found in the gut.

(4) The influence of metals on the activity of amylase was studied. Using an arbitrary mixture it was found that about 25% depression of amylase activity was brought about at levels of metals near the maximum that can be tolerated by the cacao tree.

(5) The inability of the beetle to digest insoluble carbohydrate, and the general low level of soluble carbohydrate reserves in the cacao tree indicate that it is to the advantage of the beetle to feed on trees in which carbohydrate is most abundant, or carbohydrate metabolism is most rapid. This provides a possible explanation for the greater prevalence of beetles in unshaded cacao.

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Manurial and Cultural Experiments on Cacao. Part III. River Estate and Central Experimental Station, Centeno, Trinidad

by

G. Havord, G. K. Maliphant and F. W. Cope

THE manurial and cultural field experiments laid down at River Estate have been described in the last two Reports on Cacao Research (Havord, 1953a, 1953b), where details of treatments and designs of the experiments were given. The first results of the two older experiments, planted in 1949, concerned with shade, spacing and fertilisers (Expt. I), and with spacing, mulching and trench mulching (Expt. III) were recorded during the crop year 1952/3 (1st September, 1952, to 31st August, 1953) and are described below. None of the other younger experiments bore a recordable crop in 1952/3.

I. Shade, Spacing and Fertiliser Experiment

The factors involved in the experiment are (i) permanent shade *versus* none, the shade tree being *Immortelle* (*Erythrina poeppigiana* (Walp.) O. F. Cook), at present spaced at 24×24 ft.; (ii) wide (12×12 ft.) *versus* close (8×8 ft.) spacing; and (iii) fertilisers, being ammonium sulphate, superphosphate, and potassium chloride factorially at two levels. The levels are (i) none, and (ii) a level graded according to the age of the cacao as previously described (*loc. cit.*). Clone ICS 1 is planted throughout.

Three types of data were recorded during the crop year. Those concerned with crop production were (i) yield in pounds of dry cacao per acre per plot (recorded as weight of wet cacao per plot, and converted to dry weight by multiplication by the factor 0.40), (ii) number of healthy pods harvested per tree, (iii) number of diseased pods harvested per tree. The data concerned with vegetative growth, taken during January and February, 1953, were (i) girth at ground level (or lower if branches occurred at ground level), (ii) height of the tree, (iii) "tree volume," expressed as the product of height and width in two perpendicular directions, (iv) general vigour and "bushiness" of the tree, and (v) leaf appearance, directed particularly at giving an indication of the appearance of foliar deficiency symptoms. Finally, observations were made of the intensity of flowering and fruiting during January and February, 1953. The general appearance, leaf appearance, flowering and fruiting data were recorded by visual scoring on a scale from 0 to 5.

The pod production data were recorded from the main experimental plots, and also from the guard plots. The guard plots have only two shade-and-spacing treatments, close spacing without permanent shade, and wide spacing with permanent shade, and in addition repeat the fertiliser treatments. These are 32 four-plot blocks falling into

four groups confounding the contrast between the two shade-with-spacing treatments, the NPK interaction and the interaction between them.

The rest of the data were recorded in the main experimental plots only. Throughout the experiment, the shade factor has up to now exerted little or no effect, and is therefore omitted from the details given below. The data is tabulated in the Appendix I.

CROP PRODUCTION RESULTS

The mean yield of the main plots was 264 lb. per acre, and that of the guard plots 245 lb. per acre.

Main Plots. The most pronounced effect on yield was exerted by the spacing factor (Table I), close spaced plots yielding 341 lb. per acre and wide spaced 188 lb. per acre ($P=.001$). Nitrogen and phosphate fertilisers also gave yield increases, the nitrogen response being an increase from 206 to 323 lb. per acre ($P=.001$) and the phosphate response from 231 to 298 lb. per acre ($P=.05$). Potassium fertilisers exerted a small but non-significant beneficial effect on yield.

None of the interactions attains significance. The spacing $\times$ nitrogen interaction is negative, so that the augmentative effects of close spacing and nitrogen manuring tend not to be additive. Also, the phosphate $\times$ potassium interaction is negative and approaching significance, suggesting a depression in the phosphate response by potassium fertiliser. The nitrogen and phosphate responses are additive.

Records of the number of healthy pods harvested per tree (Table II), showed that the close spaced plots yielded an average of 4.1 pods per tree and wide spaced plots 5.0 pods per tree, although the difference is not significant. The increased yields from the close spaced plots was, therefore, entirely due to the larger number of trees per acre, not to increased yield per tree—rather the tendency is the reverse. Nitrogen and phosphate fertilisers increased the average number of pods per tree from 3.2 to 5.9 and from 3.8 to 5.2 pods respectively, the difference attaining significance ($P=.01$) in the case of nitrogen but just failing to do so in the case of phosphate. The effect of potassium fertiliser was negligible. The interactions again indicate that the fertiliser responses tend to be greater on the wide spaced plots, that nitrogen and phosphate responses are additive, and that potassium appears to exert a depressing influence on the phosphate response.

Table III shows the weight of wet cacao per pod for the various treatments, calculated from the data already considered. Those factors which have resulted in an increased yield of cacao have at the same time produced pods containing less wet cacao per pod. Thus close spaced plots gave pods averaging 143 grams of wet cacao per pod, and wide spaced 148 grams per pod (very nearly significant). Trees receiving nitrogen fertiliser gave 140 grams per pod and in the absence of nitrogen fertiliser the pod content was 151 grams ($P=0.001$), the effect being most pronounced in the wide spaced plots. Phosphate fertilisers gave only small decrease in pod content, but there was a tendency (though non-significant) for phosphate to offset the reduction in pod content induced by nitrogen fertiliser. Potassium fertiliser exerted little effect. These results suggest an inverse relationship between the average pod content and the number of pods borne, and in fact a highly significant regression coefficient of -3.05 ± 0.84 was calculated, representing the diminution in weight of wet bean in grams per pod for every additional pod borne.

The records of the percentage of mature pods which were diseased (Table IV) indicate that treatments resulting in an increase in yield also resulted in an increased percentage of diseased pods. (Witches' broom disease and pod rots were not recorded separately). Thus close spaced plots gave 6.9% diseased pods, wide spaced plots 4.6% (difference nearly significant) and nitrogen fertilised plots gave 7.8% diseased pods whereas no-nitrogen plots gave 3.9% ($P=0.01$). The spacing $\times$ nitrogen interaction is significant ($P=0.05$) nitrogen fertiliser having increased the percentage of diseased pods more in the wide spaced plots (from 2.1 to 8.0%) than in the close spaced plots (from 6.3 to 7.6%). Phosphate fertiliser only very slightly increased the incidence of disease, but the significant nitrogen $\times$ phosphate interaction indicates that phosphate fertiliser materially reduced, though not eliminated, the increase in disease incidence induced by nitrogen fertiliser. The implications of these results are discussed later.

Guard Plots. The yield results from the guard plots are broadly similar to those obtained from the main experimental plots. There was a highly significant response to nitrogen fertilisers, but the increases in yield due to close spacing and phosphate fertiliser, though considerable, failed to attain significance (the spacing effect is determined with only low precision). The responses to nitrogen and phosphate fertilisers, however, were less (though not significantly so) on the close spaced plots, in contrast to the result obtained from the main plots. Potassium fertiliser induced a slight (non-significant) fall in yield and reduced the increase caused by nitrogen fertiliser, but tended to enhance the phosphate response.

As with the main plots, the number of pods borne per tree showed a trend similar to the yield responses to fertilisers, but close spaced plots, although yielding more cacao per acre, bore less pods per tree than wide spaced plots. Generally, the effect of those fertiliser treatments which produced a yield increase was again to reduce the weight of wet cacao per pod. Nitrogen fertiliser again significantly increased the percentage of mature diseased pods, although, surprisingly, potassium fertiliser decreased disease incidence in the close spaced plots and increased it in the wide spaced plots ($P=0.01$ for the interaction).

GROWTH MEASUREMENTS

Generally growth measurements have indicated responses to fertilisers similar to those obtained from the yield data. Tree girth, height, and "volume" (Tables V, VI and VII respectively) gave significant positive responses to nitrogen and phosphate fertilisers (the increase was not significant only in the "volume" response to phosphate). Close spaced trees were taller ($P=0.001$) than wide spaced trees, but spacing has not increased the girth or "volume" of the trees. Nitrogen fertiliser was the only treatment to give a significant response in the observations of general vigour and leaf appearance (Tables VIII and IX).

The spacing $\times$ nitrogen interaction was significant and negative in the measurements of girth, height and volume, indicating that the growth response to nitrogen fertiliser is greater in wide than in close spaced plots. Phosphate fertiliser also increased girth more in the wide spaced plots, and although the girth response to potassium is small and non-significant it, too, is greater on the wide spaced plots. Potassium fertiliser tended (not significantly) to depress the phosphate growth responses.

The regression of height (in feet) on stem girth (in cm.) has a very highly significant coefficient of -0.29 ± 0.042 .

FLOWERING AND FRUITING OBSERVATIONS

Nitrogen fertiliser increased the intensity of flowering and fruiting ($P=0.001$) and tended to be more effective on wide than on close spaced plots (Tables X and XI). Phosphate fertiliser increased the intensity of flowering ($P=0.05$) and tended to increase the fruiting intensity especially in the wide spaced plots, though not significantly. Spacing had no effect. Potassium fertiliser gave only small non-significant responses, but tended to depress the phosphate response in the absence of nitrogen.

DISCUSSION

The main results emerging from the analysis are the considerable yield and growth responses to close spacing and to nitrogen and phosphate fertilisers, and the absence of a response to potassium fertiliser.

The increased yield due to closer spacing is entirely due to the large number of trees per acre at the closer spacing. The self-shading effect induced by closer planting might have been expected to increase the productivity per tree at the closer spacing, but the tendency is actually the reverse. It remains to be seen in future years whether the benefit derived from close spacing in the earlier years is or is not maintained. On the other hand, close spacing might have been expected to induce spindly growth, particularly in the presence of nitrogen fertiliser. This was not so, however, as although close spaced trees were taller, the other growth factors were not affected; and nitrogen fertiliser increased the growth response on wide spaced more than on close spaced plots.

The responses to nitrogen and phosphate fertilisers are to be expected in view of the medium to low nutrient status of this soil (Havord, 1953a), but the lack of response to potassium is surprising, though this may not be necessarily maintained in subsequent crops. The tendency towards a depression of the phosphate response by potassium fertiliser although not repeated in the guard plots does suggest that, with young cacao at least, provision of adequate phosphate and potash in the absence of

adequate nitrogen induces nutrient imbalance. Work is now in progress to establish foliar diagnostic techniques to obtain further information on points such as this. The increase in yield obtained by the addition of nitrogen + phosphate fertiliser from 292 to 489 lb. per acre at the close spacing and from 20 to 277 lb. per acre at the wide spacing indicates the considerable benefit derived from the treatments even in the first crop borne.

The reduction in weight of wet cacao per pod which accompanied yield increases obtained from the treatments is of interest. This could be due either to less pulp or fewer beans per pod, or to smaller beans. Akintomide (unpublished thesis) has investigated the effect of environmental factors on the size of cacao beans, and finds that this does tend to vary inversely with the productivity status of the environment. It will be of importance to see how far this tendency develops as the trees mature, in view of the preference for large beans on the market.

The increased incidence of disease accompanying yield increases, particularly the response to nitrogen fertilisers, has also been noted elsewhere by Holliday, page 59, on older clonal cacao. This increase is not by any means sufficiently large to detract materially from the benefits of the treatments, but may be of especial interest when the trees mature and yields and responses to fertilisers may be expected to be much larger, as it may become profitable to undertake spraying to control disease. A possible explanation is higher atmospheric humidity where the trees are larger and denser. The effect of phosphate fertiliser in ameliorating the increased incidence due to nitrogen fertiliser is also of interest, and may indicate that the effect is not solely associated with increased yield or growth.

The observations of flowering and fruiting intensity were made on one occasion only, and so provide far from a complete picture. In view of the encouraging results, however, and the interesting effects of the treatments on the number of diseased pods harvested, a detailed programme has been initiated to study the intensity of flowering and the actual number of cherelles set, the number lost through cherelle wilt or disease, and the number reaching maturity, on sample trees in all treatments. This should also give information on exactly how the treatments give yield responses—whether by increasing flowering, or fruit setting, or by reducing cherelle wilt.

It will not be possible to repeat all the growth measurements every year; the size of the trees now makes measurement of height very tedious, and "volume" now has little meaning as pruning is being practised. As, however, all the data reflect similar tendencies, future growth measurements will be confined to girth measurements.

The absence of any effect from the permanent shade treatment is not unexpected, since during the first three years after planting the whole experiment has been under a uniform temporary shade of banana, which has masked the differential permanent shade, and the Immortelle trees have been too young to exert any effect other than shade. Progressive removal of the temporary shade commenced towards the end of the crop year under consideration.

II. Repetition of the Experiment on a Different Soil

A second shade, spacing and fertiliser experiment was planted on a site at the Central Experiment Station, Centeno, in 1953. The design and treatments are similar

to those at River Estate, with the addition that four clones, ICS 1, ICS 6, ICS 95 and IMC 67 are planted in each plot, instead of ICS 1 only, as at River Estate, in order to make the results of more general application. Wide spaced plots thus carry four trees of each clone, and close spaced plots carry nine of each.

The soil at Centeno, in the centre of the Northern Plain of Trinidad, is Cunupia Clay Loam to Silty-Clay (Chenery, 1952). It is an imperfectly-drained, yellowish-brown alluvial silty-clay, silty-clay-loam, or clay-loam, strongly mottled orange and darker yellowish-brown below about 12 ins. depth. Grey clay appears at about 24 ins., mottled yellowish-brown with a blue gley horizon below 4 ft. depth. The soil is acid and increasingly so with depth, and the nutrient status is low.

Plans are in hand to repeat others of the River Estate experiments at Centeno. This work is being carried out conjointly with the Cacao Agronomist of the Trinidad Department of Agriculture.

III. Spacing, Mulching and Trenching Experiment

The factors involved in this experiment are (i) spacing, 9×9 ft. *versus* 7.2×7.2 ft.; (ii) mulches, being cut bush, sugar-cane bagasse and trench mulching, and control (no treatment); and (iii) comparisons between the four clones ICS 1, ICS 6, ICS 8 and ICS 60. The treatments have been previously described in detail (*loc. cit.*).

The cut bush mulch was applied at a rate of approximately 25 tons (fresh weight) per acre in April, 1951, and again at half this rate in April, 1952, November, 1952, and April, 1953. Bagasse mulch was applied at a rate of approximately 30 tons per acre in April, 1951, and in November, 1952. Trench mulching has so far been carried out once, in April, 1951. The approximate quantities of major nutrients supplied by each mulch, up to 31st August, 1953, in lb. per acre are given below:—

		Cut bush	Bagasse	Trench mulch
N	...	486	326	345
P ₂ O ₅	...	103	142	194
K ₂ O	...	299	249	564

Similar data were recorded to that obtained from Experiment I. Many of the results from this first crop are inconclusive, so that only the more important data are presented here, viz., yields in lb. dry cacao per acre, stem girth, tree height and tree "volume," all recorded as in Experiment I. The tabulated data are given in Appendix II.

YIELD RESULTS

The mean yield of the experiment was 199 lb. dry cacao per acre. The closer spaced plots yielded 234 lb. per acre, and the wider spaced plots 165 lb. per acre. The difference lacks significance owing to the low level of precision attached to the comparison, but there can be little doubt that it reflects a real difference.

None of the mulch treatments gave significant yield responses. The data for ICS 1 and 8 were analysed together in order to avoid considerable heterogeneity in yield between clones (Tables XII and XIII). ICS 1 significantly out-yielded all the other clones, and performed particularly

well at the close spacing, giving 463 lb. per acre (Table XII). ICS 60 gave only low yields, but these trees are one year younger than the others, being planted in 1950 owing to delay in the availability of planting material. ICS 6 was definitely very poor, giving only 93 lb. per acre.

GROWTH MEASUREMENTS

There was no significant difference in growth measurements between spacings, though close spaced trees were taller than wider spaced trees, as in Experiment I. Trees of ICS 60 had smaller girths than all other clones ($P=.001$), and ICS 1 exceeded all other clones in girth ($P=.05$ for ICS 6, $P=.001$ for ICS 8). Also, ICS 1 and ICS 8 had significantly greater heights and "volumes" than ICS 6 and ICS 60.

Tree girth, unlike yield, was significantly effected by mulches. Thus, considering all clones, trench mulching gave greater girth than control. In the case of ICS 1, trench mulched plots gave greater girth than the other mulched treatments, and nearly significantly greater than control, and with ICS 8 bagasse mulched trees had greater girth than control. Mulch treatments did not affect tree height and "volume."

DISCUSSION

The main results to emerge from the analysis are the strikingly better performance of ICS 1 than the other clones, especially at the closer spacing. The poor yield obtained from ICS 6 is surprising, as it is very different from the encouraging early yields of this clone in the CRB experiments (Cheesman, 1944). ICS 60 has yielded well since these trees, as noted above, were only three years old at

the end of the crop year. It will be of interest to see how long the improved yield from the very close spacing of 7.2×7.2 ft. is maintained. Already very severe pruning is necessary, and root competition may rapidly become apparent.

The lack of marked response to mulching is doubtless due to the youth of the trees. Surface mulching is, of course, a slower-acting treatment than fertilisers, since its action depends on the building up by the decomposition of the mulch of a soil surface layer having optimum physical properties and rich in nutrients, protected from deterioration by constant replenishment. With trench mulching, the cacao roots may have hardly yet reached the trenches. Systematic studies of the soil under the various treatment are now (early 1954) in progress, and have shown that readily discernible improvements in the chemical and physical properties of the top layer of soil are already apparent under the surface mulches. The soil and roots in the trenches are also to be examined.

Summary

The results of two of the cultural and manurial experiments at River Estate for their first crop year are presented and discussed in detail. The main results were a considerable response to nitrogen and phosphate fertilisers, and an increased yield from close spacing. Yield increases were accompanied by an increase in disease incidence, and by a smaller weight of cacao per pod. Shade had not yet had any effect. Mulches did not significantly affect yields or growth, and ICS 1 markedly outyielded ICS 8 and ICS 6, the latter clone being particularly poor in its first crop year.

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Appendix I

TABLE I

Yields in pounds of dry cacao per acre for combinations of spacing and manuring in Experiment I.

		N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	292	224	273	489	263	478	365	342	341
Wide spacing ...	20	248	201	277	126	199	109	327	188
Means ...	156	236	237	384	195	339	237	335	264

S.E. of difference of spacing means ± 27.8

S.E. of difference of manuring means ± 55.7

S.E. of difference, same row or column, body of table ± 78.8

d.f. error=28.

TABLE II

Mean healthy pod production per tree for combinations of spacing and manuring in Experiment I.

	—	N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	3.3	2.7	3.2	5.8	3.0	5.9	4.3	4.2	4.1
Wide spacing ...	0.5	6.7	5.2	7.3	3.4	5.5	2.7	8.9	5.0
Means ...	1.9	4.7	4.2	6.6	3.2	5.7	3.5	6.6	4.6

S.E. of difference of spacing means ± 0.73 .S.E. of difference of manuring means ± 1.47 .S.E. of difference, same row or column, body of table ± 2.08 .

TABLE III

Mean pod content, in grams of wet cacao, for combinations of spacing and manuring in Experiment I.

	—	N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	147	144	144	140	150	135	141	139	143
Wide spacing ...	162	139	150	146	154	138	157	139	148
Means ...	155	142	147	143	152	137	149	139	146

S.E. of difference of spacing means ± 2.8 .S.E. of difference of manuring means ± 5.5 .S.E. of difference, same row or column, body of table ± 7.8 .

TABLE IV

Transformed percentage pod loss from disease, for combinations of spacing and manuring in Experiment I.

	—	N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	11.92	15.02	17.31	15.85	13.84	17.33	14.89	15.68	15.23
Wide spacing ...	4.20	18.50	11.31	12.93	8.23	20.00	9.81	14.47	12.43
Means ...	8.06	16.76	14.31	14.39	11.04	18.67	12.35	15.08	13.83

S.E. of difference of spacing means ± 1.43 .S.E. of difference of manuring means ± 2.85 .S.E. of difference, same row or column, body of table ± 4.04 .

TABLE V

Mean tree girth, in cm., for combinations of spacing and manuring in Experiment I.

	—	N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	24.8	24.1	25.5	26.6	23.6	27.0	25.2	25.1	25.2
Wide spacing ...	18.6	26.4	25.4	26.4	21.6	26.4	22.8	28.1	24.5
Means ...	21.7	25.3	25.5	26.5	22.6	26.7	24.0	26.6	24.9

S.E. of difference of spacing means ± 0.65 .S.E. of difference of manuring means ± 1.30 .S.E. of difference, same row or column, body of table ± 1.84 .

TABLE VI

Mean tree height, in feet, for combinations of spacing and manuring in Experiment I.

	—	N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	9.16	8.06	9.11	9.48	8.56	9.18	8.97	9.04	8.95
Wide spacing ...	6.17	8.51	8.42	8.74	7.69	8.62	7.30	8.83	8.04
Means ...	7.67	8.29	8.77	9.11	8.13	8.90	8.14	8.94	8.49

S.E. of difference of spacing means ± 0.23 .S.E. of difference of manuring means ± 0.47 .S.E. of difference, same row or column, body of table ± 0.66 .

TABLE VII
Mean tree volumes, in cu. ft., for combinations of spacing and manuring in Experiment I.

	—	N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	664	523	648	714	581	744	683	711	659
Wide spacing ...	280	744	730	748	540	690	448	837	627
Means ...	472	634	689	731	561	717	566	774	643

S.E. of difference of spacing means ± 47.3
S.E. of difference of manuring means ± 94.6 .
S.E. of difference, same row or column, body of table ± 133.6 .

TABLE VIII
Mean values of scores (range 1.42 to -1.42) for general appearance of trees for combinations of spacing and manuring in Experiment I.

	—	N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	0.20	0.40	0.30	0.16	-0.24	0.37	-0.43	0.33	0.14
Wide spacing ...	-1.28	0.15	-0.02	0.50	-0.76	0.32	-0.33	0.32	-0.14
Means ...	-0.54	0.28	0.14	0.33	-0.50	0.35	-0.38	0.33	0.00

S.E. of difference of spacing means ± 0.22 .
S.E. of difference of manuring means ± 0.43 .
S.E. of difference, same row or column, body of table ± 0.61 .

TABLE IX
Mean values of scores (range 1.42 to -1.42) for general appearance of leaves on trees for combinations of spacing and manuring in Experiment I.

	—	N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	0.00	0.52	0.05	0.24	0.10	-0.10	-0.41	0.89	0.16
Wide spacing ...	-1.35	0.10	0.36	0.47	-0.60	-0.20	-0.47	0.39	-0.16
Means ...	-0.68	0.31	0.21	0.36	-0.25	-0.15	-0.44	0.64	0.00

S.E. of difference of spacing means ± 0.23 .
S.E. of difference of manuring means ± 0.46 .
S.E. of difference, same row or column, body of table ± 0.65 .

TABLE X
Mean values of scores (1.42 to -1.42) for intensity of flowering for combinations of spacing and manuring in Experiment I.

	—	N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	-0.90	-0.13	0.13	0.72	0.21	0.49	-0.11	0.33	0.09
Wide spacing ...	-1.29	0.04	-0.47	0.56	-0.57	0.41	-0.20	0.80	-0.09
Means ...	-1.10	-0.05	-0.17	0.64	-0.18	0.45	-0.16	0.56	0.00

S.E. of difference of spacing means ± 0.21 .
S.E. of difference of manuring means ± 0.43 .
S.E. of difference, same row or column, body of table ± 0.61 .

TABLE XI
Mean values of scores (1.42 to -1.42) for intensity of fruiting for combinations of spacing and manuring in Experiment I.

	—	N	P	NP	K	NK	PK	NPK	Means
Close spacing ...	-0.76	0.25	0.32	0.13	0.09	0.64	-0.51	0.25	0.05
Wide spacing ...	-1.29	0.00	-0.06	0.71	-0.60	0.45	-0.77	1.16	-0.05
Means ...	-1.03	0.13	0.13	0.42	-0.26	0.55	-0.64	0.71	0.00

S.E. of difference of spacing means ± 0.19 .
S.E. of difference of manuring means ± 0.39 .
S.E. of difference, same row or column, body of table ± 0.45 .

Appendix II

TABLE XII

Mean yields, in lb. dry cacao per acre, for combinations of spacing and clones in Experiment III.

				ICS 1	ICS 8	Means	ICS 6	ICS 60*
Close spacing ...	...	...	...	463	226	344	97	148
Wide spacing ...	...	...	...	250	251	250	89	70
Means ...	...	...	...	356	238	297	93	109

S.E. of difference of means of ICS 1 and ICS 8 ± 36 .

S.E. of difference of ICS 1 and ICS 8 at same spacing ± 51 .

TABLE XIII

Mean yields, adjusted for confounding, for combinations of mulch treatments and clones in Experiment III.

				ICS 1	ICS 8	Means
Bagasse ...	...	...	...	280	316	298
Cut bush...	...	...	...	358	267	312
Trenched ...	...	...	...	350	200	275
Control ...	...	...	...	438	171	304
Means ...	...	...	...	356	238	297

S.E. of difference of mulch means ± 51 .

S.E. of difference (average value) within body of table ± 93 .

TABLE XIV

Mean girth, in cm., for combinations of spacing and clones in Experiment III.

				ICS 1	ICS 6	ICS 8	ICS 60*	Means
Close spacing ...	...	...	...	29.14	25.26	25.15	18.91	24.62
Wide spacing ...	...	...	...	27.02	26.93	24.75	17.57	24.07
Means ...	...	...	...	28.08	26.10	24.95	18.24	24.34

S.E. of difference of clone means ± 0.84 .

S.E. of difference in same row, body of table ± 1.19 .

TABLE XV

Mean girth in cm., adjusted for confounding, for combinations of mulch treatments and clones in Experiment III.

				ICS 1	ICS 6	ICS 8	ICS 60*	Means
Bagasse ...	...	...	...	15.15	24.67	26.73	20.08	24.16
Cut bush ...	...	...	...	27.78	26.60	26.25	17.38	24.50
Trenched ...	...	...	...	31.44	27.18	24.06	18.74	25.36
Control ...	...	...	...	27.97	25.92	22.75	16.77	23.35
Means ...	...	...	...	28.09	26.09	24.95	18.24	24.34

S.E. of difference of mulch means ± 0.84 .

S.E. of difference (average value) within body of table ± 1.86 .

TABLE XVI

Mean height, in feet, for combinations of spacing and clones in Experiment III.

				ICS 1	ICS 6	ICS 8	ICS 60*	Means
Close spacing ...	...	...	...	10.03	9.33	8.38	7.56	8.83
Wide spacing ...	...	...	...	8.96	9.39	8.48	6.72	8.39
Means ...	...	...	...	9.50	9.36	8.43	7.14	8.61

S.E. of difference of clone means ± 0.27 .

S.E. of difference in same row of body of table ± 0.39 .

* ICS 60 was one year younger than the other clones.

TABLE XVII

Mean height, in feet, adjusted for confounding, for combinations of mulch treatments and clones in Experiment III.

				ICS 1	ICS 6	ICS 8	ICS 60*	Means
Bagasse	...	...	...	8.92	9.30	8.52	7.57	8.58
Cut bush	...	...	...	9.95	9.02	8.77	6.52	8.57
Trenched	...	...	...	9.78	9.74	8.29	7.63	8.86
Control	...	...	...	9.34	9.37	8.15	6.84	8.43
Means	...	...	...	9.50	9.36	8.43	7.14	8.61

S.E. of difference of mulch means ± 0.27 .

S.E. of difference (average value) within body of table ± 0.61 .

TABLE XVIII

Mean volume, in cu. ft., for combinations of spacing and clones in Experiment III.

				ICS 1	ICS 6	ICS 8	ICS 60*	Means
Close spacing	...	...	...	900	678	468	499	636
Wide spacing	...	...	...	778	836	568	405	647
Means	...	...	...	839	757	518	452	642

S.E. of difference of clone means ± 56 .

S.E. of difference in same row, body of table ± 80 .

TABLE XIX

Mean tree volume, in cu. ft., adjusted for confounding, for combinations of clones and mulch in Experiment III.

				ICS 1	ICS 6	ICS 8	ICS 60*	Means
Bagasse	...	...	...	692	741	497	471	600
Cut bush	...	...	...	907	783	584	377	663
Trenched	...	...	...	914	781	540	495	683
Control	...	...	...	842	723	452	467	621
Means	...	...	...	893	757	518	453	642

S.E. of difference of means ± 56 .

S.E. of difference (average value) within body of table ± 125 .

* ICS 60 was one year younger than the other clones.

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